METALLURGY OF TIN

Published by the
McGraw-Hill Book Company
New York

Successors to the Book Departments of the
McGraw Publishing Company Hill Publishing Company

Publishers of Books for
Electrical World
The Engineering and Mining Journal
Engineering Record
Power and The Engineer
Electric Railway Journal
American Machinist
Metallurgical and Chemical Engineering

AN ANCIENT FURNACE
(Reproduction taken from Agricola's "De Re Metallica" — 1561)

METALLURGY

OF

TIN

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McGRAW-HILL BOOK COMPANY

239 WEST 39TH STREET, NEW YORK

6 BOUVERIE STREET, LONDON, E.C.

1911

THE PLIMPTON PRESS NORWOOD MASS. U.S.A.

PREFACE

THIS little work is in the main a reprint of a monograph on the metallurgy of tin, published originally in *Mineral Industry* for 1896, Vol. V. Authentic information on the subject of tin smelting is somewhat scarce, and as the above-mentioned volume of *Mineral Industry* has long been out of print, it was decided to issue the monograph as a separate work, incorporating in it as much recent information on the subject as was obtainable. The small amount of new matter is due to two reasons: firstly, the unprogressive character of tin smelting, which continues from decade to decade with comparatively little change, and, secondly, the profound degree of secrecy observed by tin smelters, who are extremely anxious to keep to themselves any modifications or improvements in the processes of tin smelting. To what extent these two facts, the slow advance of the industry and the secretive habits of those engaged in it, are related as effect and cause, may be left to the judgment of the reader.

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NEWCASTLE-ON-TYNE, ENGLAND.
June, 1911.

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CHAPTER I

Properties and Occurrence of Tin

Physical Properties. — Tin is a metal of a pure white to slightly bluish-white color. It is highly malleable, but somewhat less ductile, its tensile strength being low; this is usually given as about 4,600 lbs. to the square inch; most impurities tend to increase the strength; some careful tests by the author on very pure cast bars 0.25 inch thick gave 2,420 lbs. per square inch, with an average elongation of 37 per cent. on a 3-inch test piece; the same tin hammered down to 0.15 inch gave a tensile strength of 2,540 lbs. per square inch with 59% elongation. The strength of strips of pure tin-foil (96% pure), 1 inch wide, 0.00026 inch thick, was found to be 1.535 lbs., equal to 5,980 lbs. per square inch. It is most malleable at about 100° C. and is brittle at about 200° C. It is capable of being rolled into thin sheets (tin-foil) as little as $\frac{1}{5000}$ inch in thickness. Its specific gravity is 7.28 (Jager and Dieselhorst), 7.287 when cast and 7.30 when rolled; that of the tetragonal form of tin, deposited electrolytically (see Fig. 1) is 7.25 * and of rhombic tin 6.55; that of ordinary commercial tin is about 7.5, most of the impurities usually present being heavier than tin itself. Its melting point is given variously between 227° and 235° C.; it forms a very mobile fluid when molten. Under certain conditions, including low temperatures, tin crumbles down into a gray, friable granular powder, which is generally considered to be an allotropic modification and has a specific gravity of about 5.8. This property of tin may be attended with serious consequences, and has there-

* Cohen and Goldschmidt, Zeitsch. f. Phys. Chem., Vol. 50, 1905, p. 221.

fore been the subject of much study, especially in Holland,* where it is spoken of as "Tinpest" or "Tin sickness." It appears to have been first observed by O. L. Erdmann in 1851, and then again by Fritzsche, whose attention was called to the fact that some blocks of Banka tin lying in a customs warehouse at St. Petersburg had fallen into dust;

FIG. 1. — Crystals of Electrolytic Tin
Magnified 30 diameters
After Mr. J. E. Stead, F.R.S.

he found that this transformation was due to exceptionally low temperature. Rammelsberg investigated the subject in 1870 and again in 1880; he pointed out that the gray modification of tin has a low specific gravity (5.770 to 5.957),

* E. Cohen and C. van Eyk, Zeitsch. f. Phys. Chem., Vol. 30, 1899, p. 601.

Tinpest en Museumziekte, by Prof. Ernst Cohen, "De Ingénieur," 1908, p. 529.

which increased gradually on heating it above 165° to 6.683 and at 200° C. to 6.91; he came to the conclusion that the change was not due solely to low temperature, and noted that electrolytic tin was not affected in this way on cooling it. Cohen has shown that the change to the gray modification is a slow process, and that it depends both on the temperature and on the length of exposure to it. The change commences at a temperature of + 18° C. at which it takes place with extreme slowness, the maximum rate being attained at — 48° C., below which it again becomes less rapid. If any object, in which the change has commenced, is allowed to remain at ordinary temperatures, the formation of gray tin continues, since the particles of gray tin, once formed, act as fresh catalytic centers. It is on this account that Cohen has given the name of *tinpest* to this transformation.

Tin boils at from 1500° to 1600° C. if heated out of contact with air; heated to this temperature in the air it takes fire, burning with a white flame; heated in the air at lower temperatures it readily gives off white fumes, but loses very little weight; heated for some time in the air it is gradually converted into a yellowish-white mass of stannic oxide, known as "putty powder." It is very little affected by exposure to air at ordinary temperatures, even in the presence of moisture.

Tin appears to be dimorphous and to crystallize in both the rhombic and the tetragonal systems, an example of the latter form being shown in Fig. 1; it would appear that the rhombic tin is brittle, whereas the common tetragonal tin is malleable; the latter changes to the former at about 170° to 200° C., thus giving rise to the brittleness of the metal at this temperature. Tin shows a very marked tendency to crystallize on solidification, and has always a more or less crystalline structure. When a bar of tin is bent, it emits a low crackling noise, the so-called "cry" of tin due apparently to the rubbing of the crystals against each other.

The conductivity of tin for heat is 15.2 and for elec-

tricity 14.4, silver in each case being taken at 100. Its specific heat is 0.0562, and its expansion by heat 0.00223 from 0° to 100° C. When molten tin is allowed to solidify, its volume decreases 6.75%.

Chemical Properties. — Tin is quadrivalent; its atomic weight is 119 (Oxygen = 16). Tin may be described as having low chemical affinities, and thus in some respects approximating to the precious metals in its chemical behavior. It is readily attacked by chlorine and by hydrochloric acid, is soluble in sulphuric acid, but is merely oxidized by nitric acid, not forming any nitrates.

Oxides. — Tin combines with oxygen to form two oxides, stannous, SnO, and stannic, SnO_2, the latter being by far the most important compound of the metal. Stannic oxide occurs native as cassiterite, which is at times almost pure stannic oxide, crystallizing in the tetragonal system; when the vapor of stannic chloride and water vapor are passed together through a red-hot tube, crystals of stannic oxide are formed which belong to the rhombic system. Stannic oxide is infusible, is not soluble in acids, and is but little affected by any ordinary reagents. On fusion with alkalies it forms alkaline stannates having the general formula R_2SnO_3; the salts of soda and potash are well known in their hydrated forms, in which they readily crystallize.

Stannic oxide when pure is white to straw yellow in color. It is reduced to the metallic state by heating to low redness in a current of hydrogen; on the other hand, metallic tin decomposes water vapor at a red heat, forming stannic oxide and hydrogen. It is also reduced by carbonic oxide, and at a low temperature by fusion with potassic cyanide, the latter reaction being made use of in tin assaying. It is reducible to the metallic state by heating with carbon, but the reaction is strongly endothermic and takes place only at a very high temperature, approaching a white heat.

Stannous oxide, SnO, is a dark gray to grayish-black powder which burns like tinder when heated in air, forming

stannic oxide. Stannous stannate, Sn_2O_3, is said to exist, but has been very little examined.

Chlorides. — Stannic chloride, $SnCl_4$, is produced by the action of chlorine gas upon metallic tin; it forms a colorless fluid, solidifying at —33° C., fuming when exposed to the air, owing to the absorption of moisture, and boiling at 124° C.

Stannous chloride, $SnCl_2$, is produced by the action of dry hydrochloric acid gas upon metallic tin. When tin is dissolved in hydrochloric acid, hydrated stannous chloride is produced, which when crystallized is known commercially as "tin-salt." The anhydrous chloride is a white solid, melting at 250° C. and boiling at 610° C. When a solution of stannous chloride is added to one of auric chloride, a purple or purplish-brown precipitate, known as "Purple of Cassius," is produced.

Phosphides. — When tin is heated in phosphorus vapor, or when phosphorus is dropped into molten tin, phosphides are produced, the one that contains the highest proportion of phosphorus having the composition SnP. On heating this or any of the other phosphides, a phosphide having the composition Sn_9P is left; this forms a gray crystalline mass, melting at 370° C.

Sulphides. — Tin forms two sulphides, SnS and SnS_2; the first named is the more stable and is produced when tin and sulphur are heated together.

Silicates. — Very little is known respecting these; the following information is mainly derived from experimental work by Mr. H. Dean, A.R.S.M., M.Sc., in the author's laboratory at Armstrong College, Newcastle-on-Tyne.

There is no stannic silicate; when SnO_2 and SiO_2 are heated together in the air, even to a full white heat, no combination takes place. In the presence of alkalies or alkaline earths, the mass fuses readily, forming a homogeneous opaque glass, which is probably a silico-stannate of the base added. It is probably this substance that is formed when stannic oxide is fused with glass, and which renders it opaque; this

fact is made use of in the preparation of various opaque enamels, etc.

Stannous silicate is produced when stannous oxide is heated with silica, or when stannic oxide and silica are heated together in the presence of a reducing agent. It forms a pale yellow, resinous substance, very limpid when melted, which cannot be completely reduced to the metallic state by fusion with reducing agents. There are probably several stannous silicates, as stannous oxide and silica appear to unite on heating throughout a wide range of different proportions. It is highly probable that tin slags contain both stannous silicates and various silico-stannates.

Alloys of Tin. — Tin alloys readily with most other metals, many of its alloys being useful in the arts; its property of alloying with iron is utilized in the manufacture of tin-plate. The most usual impurities of tin are iron, arsenic, sulphur, antimony, bismuth, lead, and copper; the effect of most of these is to diminish the ductility of tin, and to render its color grayer and its luster duller.

The alloy of *tin* and *iron* is really the only one that affects the extraction of the former metal, or that needs extended notice here. As obtained, in a more or less pure condition, in smelting operations, in the crucibles or forehearths, or on the beds of furnaces, when it is known as "hardhead," it forms a pale to dark-gray, irregularly granular or crystalline, brittle, more or less completely fused mass, and generally consists of more or less metallic tin mechanically intermingled with alloys of definite composition, that appear to be true chemical compounds. The commonest and best known is $FeSn_2$, which should contain Fe 19%, Sn 81%. This has been carefully studied by Oudemans,* who has isolated it in crystals from Banka tin and finds its specific gravity to be 7.743. This seems to be the alloy that generally forms when ferriferous tin is melted and allowed to cool slowly, the excess of tin being subse-

* *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indie,* 1890, I, p. 24: "Over verontreiniging van Banka Tin."

quently dissolved in hydrochloric acid. It appears to have been described and analyzed by Plattner, and also by Nöllner in the year 1860.

Caron and Deville have described an alloy of the composition FeSn. Lampadius, Berzelius, Berthier, and Stölzel describe alloys from hardheads of Altenberg of the composition Fe_4Sn (Sn 30.5%, Fe 61.5%). Stölzel has obtained alloys of the formulas $FeSn_6$ and $FeSn_7$ in quadratic prisms from Schlaggenwald, and Lassaigne has described one of the composition Fe_3Sn. Stölzel says that whenever any alloy containing more than two-thirds its weight in tin is melted, tin liquates away, leaving the alloy FeSn behind.

The alloys as ordinarily obtained appear to be complex in character, and it is probable that true chemical compounds may often be produced; the alloy of 50% iron and 50% tin seems to have the lowest melting point, namely 1140°C.

Hardhead as produced in smelting operations upon impure ore nearly always contains arsenic; D. M. Levey and D. Ewen * state that the proportions of iron, tin, and arsenic approximate to 2:1:1.

They give the analysis of one sample as:

Sn	17.92%
As	21.92
Fe	52.90
S	1.90
Insoluble	2.03
	96.67

The following analyses are given by M. J. T. Holloway:†

	1	2	3	4	5
Sn (Total)	31.4%	25.2%	36.5%	29.0%	22.5%
Fe	58.3	64.0			
As	7.1	6.0	29.5	5.2	4.2
S	2.9	4.1			
Sn present as prill	3.0	2.0	8.5	19.5	7.5

Nos. 1 and 2 are bulk samples from both ore and slag smelting, 1906; No. 3 from ore smelting, 1903; No. 4 from

* "The Bessemerizing of Hardhead," by D. M. Levey and D. Ewen, *Trans. Inst. M. M.*, Vol. XVIII, 1908, p. 466.

† *Ibid.*, p. 477.

ore smelting, 1907; No. 5 from slag smelting, 1907. All these hardheads came from Cornwall.

Tin and *copper* alloy readily; according to Heycock and Neville,* three of the alloys, corresponding respectively to

FIG. 2

Tin....................................75%
Antimony..............................25%
Magnified 50 diameters
After Mr. J. E. Stead, F.R.S.

the formulas SnCu, $SnCu_3$ and $SnCu_4$, appear to form compounds, and to remain practically homogeneous after cooling. The alloy containing 17% of tin and 83% of copper appears to have the greatest tensile strength, namely about 36,000 lbs. to the square inch, while those containing between 75 and 25% of copper have practically no extensibility. The

* *Philosophical Transactions,* 1904.

alloys used in the arts all contain a considerable proportion of copper; that with 65 to 70% of copper and 30 to 35% of tin is known as *Speculum metal;* it is gray in color, hard, brittle, breaks with a conchoidal fracture, and takes a high polish. Alloys that contain more than 73% of copper are no longer brittle, are usually spoken of as bronzes, and are softer the more copper they contain. Bell metal, dense and sonorous, contains 75 to 85% of copper, statuary bronze up to 90% of copper, often with 1 to 2% of zinc also, and gun metal about 92% of copper. This latter alloy has a tensile strength of about 16 tons per square inch, an elastic limit of 6.5 tons per square inch, and an elongation of about 16%. Bronze for coinage contains 4 to 5% of tin.

Phosphor-bronze contains about 9 parts of copper to 1 of tin and 0.25 to 2.5% of phosphorus, with at times a little lead. That with less than 0.5% of phosphorus is particularly tough and elastic, and is used for parts of machinery when these qualities are of special importance; alloys high in phosphorus are very hard and are especially adapted for bearing metals.

Tin and *lead* alloy in all proportions, forming neither compounds nor solid solutions; the eutectic contains 37% of lead and melts at 180° C.; solders are alloys of lead and tin, in which the proportions of the former to the latter metal vary from 2 : 1 to 1 : 2, the alloy being more fusible the larger the amount of tin that it contains up to the eutectic limit.

Pewter consists of lead and tin in the proportion of about 1 : 4, a little antimony or copper being often added; in France the maximum amount of lead admissible is 18%.

Tin amalgamates readily with *mercury;* this amalgam was at one time used largely for "silvering" the backs of mirrors. The amalgam containing 50% of mercury is solid, those containing more mercury are pasty, and those with over 90% of mercury liquid.

Tin and *antimony* alloy readily, but the constitution of the alloys is complex, as indicated by the accompanying

microphotographs, after Mr. J. E. Stead (Figs. 2 and 3); Fig. 4 shows the effect of a small percentage of arsenic upon the form of the crystals. Those alloys containing 80 to 90% of tin, and usually a little copper as well, form Britannia Metal, and are also used as white metal for bearings; sometimes in the cheaper qualities a considerable

FIG. 3

Tin	85%
Antimony	25%

Magnified 50 diameters
After Mr. J. E. Stead, F.R.S.

proportion of the tin is replaced by lead. A triple alloy of lead, tin, and antimony, with 10 to 20% of tin, is much used for bearings. An alloy of tin, zinc, and antimony is used by dentists under the name of Meter Metal. Babbitt's Metal consists essentially of zinc with about 20% of tin added to it. Alloys of zinc, antimony and tin, with from 5 to 40 % of tin, are used for the bearings of heavy, slow-running machinery. Alloys of zinc and tin have been used for small patterns, and by dentists for dies.

Silver and *tin* alloy readily; their eutectic contains 3.5% of silver and 96.5% of tin and melts at 220° C. Amal-

gams of a silver-tin alloy are largely used by dentists for stopping teeth. Dental amalgams contain from 30 to 50% of mercury, the alloys used ranging from 40% to 60% of

FIG. 4

Tin	75%
Antimony	20%
Arsenic	5%

Magnified 30 diameters
After Mr. J. E. Stead, F.R.S.

silver, or sometimes even more; the quickest setting amalgam is said to be that made from the alloy containing 72.5% of silver and 27.5% of tin.

Gold and *tin* alloy readily; those containing over 2% of tin are brittle.

Fusible metals are alloys containing tin, lead, bismuth, and cadmium in various proportions, the tin ranging from 10 to 20%. The eutectic alloy of lead, tin, and bismuth

expands on cooling; it melts at 94° C. and contains 32% of lead, 16% of tin, and 52% of bismuth. The eutectic tin-bismuth alloy contains 44% of tin, and melts at 124° C.

Ores of Tin. — Practically the only ore of tin is tinstone or cassiterite, SnO_2. A complex sulphide of tin, stannite or bell-metal ore, consisting of the sulphides of tin, copper, iron, and occasionally also of zinc, is known, but is a rare mineral and is to be looked upon rather as a mineralogical curiosity than as an ore of the metal.

Cassiterite is found in two main forms differing in their mode of occurrence, namely "vein tin" and "stream tin." (It may be noted that miners usually speak of tinstone as "tin," or more often as "black tin," using the term "white tin" to designate the metal.) Vein tin is the ore that is obtained from mineral veins or lodes, or from stockworks or disseminations, *i.e.*, from primary deposits, whilst stream tin is the ore in rounded lumps or grains obtained from alluvial deposits, which are secondary or clastic, being derived from the disintegration of the primary deposits.

The country rock of the former class is nearly always granitic, or else the deposits are closely related to dykes or masses of granitic rock in their vicinity. The accompanying minerals are therefore usually quartz, feldspar, and mica; other accessory minerals, many of which contain fluorine, such as tourmaline, topaz, fluorspar, apatite, occur with tinstone, and a number of other metalliferous minerals, such as iron pyrites, arsenical pyrites, wolfram, copper pyrites, etc., also occur, some of them being often very closely associated with the tinstone. Vein tin is thus always a more or less impure mineral.

Stream tin, on the contrary, although produced simply by the degradation of such deposits, has been long exposed to the oxidizing influences of air and water, which have removed practically all the impurities, these having been weathered and dissolved away, the extremely hard, heavy, and chemically inert cassiterite resisting the natural agencies that have destroyed the other minerals. Hence it is that

stream tin merely requires washing in a simple trough washer in order to remove the clay, sand, etc., with which it is intermixed; the heavy residue then consists of grains of cassiterite together usually with titaniferous iron ore, magnetite, and at times wolfram. The two former are removed by careful washing; the latter cannot thus be separated, but can be removed magnetically.

The treatment of vein-stuff carrying tin ore is much more complex, as it is indispensable for economic and technical reasons that the ore be freed as far as possible from impurities before smelting. As tinstone occurs in a very fine state of division in its gangue, the crude "tin-stuff" must in the first place be crushed down to about 0.05 inch, usually in stamp-mills. The crushed stuff is then submitted to a series of washing operations by which the lighter non-metallic minerals are removed, whilst the heavier metalliferous portion remains behind in a concentrated form known in Cornwall as "whits." This latter contains tinstone, iron pyrites, and arsenical pyrites, and any copper pyrites and wolfram that may be present. This is then calcined at a low red heat, by which means the pyrites are decomposed, sulphurous anhydride and arsenious oxide being evolved; the latter is condensed in flues and collected. The residue is again washed, when the light oxide of iron that results from the oxidation of the pyrites is readily removed. If a small amount of copper is present this is also got rid of as a soluble sulphate. Wolfram is not affected by calcination and has so nearly the same specific gravity as tinstone that it cannot be separated from it by any form of washing. It was formerly separated by the Oxland process, which consists in fusing the ore with soda-ash or black-ash on the bed of a reverberatory furnace; the wolfram (tungstate of iron and manganese) is thereby decomposed, soluble tungstate of soda is produced, and the iron and manganese are left as light flocculent oxides that are easily washed away. This process is troublesome and costly and causes some loss of tin, owing to the formation of sodic stannate. The

modern method consists in submitting the calcined whits to magnetic separators of the Wetherill type, by which the residue from the calcination of the pyrites as well as the wolfram are attracted and removed.* The final product in either case is black tin containing 60 to 65% of metallic tin. The crude tin-stuff as it goes to the stamps does not as a rule contain more than 40 to 50 lbs. of black tin to the ton of stuff. Stream tin, on the other hand, usually contains well over 70% of metallic tin.

Tin ore occurs in relatively few localities in the world, and tin ranks as the rarest of all the common metals. The chief sources of the world's supply are the following:

Malay Peninsula. — The ore is chiefly stream tin, derived from vast alluvial deposits, situated chiefly along the west coast of the Peninsula in the states of Perak and Selangor; some of the other states, notably Negri Sembilan and Pahang, also produce tin. The total production probably corresponds to about 60,000 tons of metallic tin annually.

Malay Archipelago. — Many of the islands of the archipelago contain deposits of alluvial tinstone, the most important being the Dutch colonies of Banka and Billiton; their annual output is about 15,000 tons of tin.

Smaller outputs are obtained also from Siam, especially from the isthmus of Kra, and from Burma. China, Tonkin, Manchuria, Siberia, Korea, Persia, and Japan are all stated to produce more or less tin, but their production is unimportant, with the exception of the mines near Mengtze, Yunnan, which appear to produce about 4000 tons of tin yearly.

Bolivia. — The production here is practically all vein tin, and is often very impure, the veins carrying numerous other minerals; it is equivalent to about 20,000 tons of metal yearly.

Australasia. — The colony of Tasmania is the principal producer, but tin ore is found also in Queensland, New South

* For full details of these operations see *The Dressing of Minerals*, by H. Louis, p. 524.

Wales, West Australia, and Victoria; the total output is equivalent to about 8,000 tons of metal, and is produced in the form of both vein tin and stream tin.

Cornwall. — The annual production is about 6,000 tons of metal, derived wholly from vein tin. In Europe small productions are recorded also from Spain, Portugal, Saxony and Austro-Hungary, but these are quite unimportant. Spain produces about 70 tons; quite recently tin has been discovered near Cartagena.

Africa. — Tin ore is being produced in the Transvaal and in Swaziland, whilst systematic mining is commencing in Nigeria, chiefly in the province of Bauchi in Northern Nigeria, where tin has been produced for a long time past by the natives. Tin has also been found in the Congo States. The production of Africa may be put down at about 3,000 tons of tin annually at present; in 1908 Nigeria exported to Great Britain 464 tons of tin ore and 22 tons of bar tin; Portugese East Africa, exported 2076 tons, and British South Africa 66 tons of tin ore to Great Britain in the same year.

North America. — There is a small production from Mexico, but practically none from the United States.

The world's annual production of tin may therefore at present (1910) be taken to be about 110,000 to 115,000 tons per annum. There is, furthermore, a considerable production of tin recovered from old tin-plate scrap; this industry is carried on mainly in Germany and the United States of America, and the amount thus obtained may be approximately estimated at about 3,000 tons.

The table on the following page shows the world's output of tin ore as estimated by three important authorities, all the weights being metric tons.

Assay of Tin Ores. — The assayer has two classes of materials to deal with, namely: (1) rich materials such as concentrated tinstone or black tin, and (2) poor materials, such as crude tin ore, this being either alluvial or vein-stuff, tailings, etc.

WORLD'S PRODUCTION OF TIN

	A	B	C
Federated Malay States	51,653	61,540	61,522
Siam	5,019		
Dutch East Indies	17,141	14,430	14,440
Great Britain	5,133	5,000	5,287
Australia	8,950	6,450	5,470
China	4,836	not included	4,267
Bolivia	17,926	20,880	18,412
Northern Nigeria	370		not included
Swaziland	478		
Transvaal	840		
Minor Producers	612		
Total	112,958	108,300	109,398

A. Production for 1908, "Mines and Quarries: General Report and Statistics." Part IV, 1910, p. 281.

B. Production for 1909. "Statistische Zusammenstellungen von der Metallgesellschaft, Frankfurt a. M." 1910, p. 14.

Production for 1909. *The Mineral Industry*, Vol. XVIII, p. 664.

Assay of Black Tin. — The sample of ore is ground very fine, say to pass a 100-sieve — and is then digested for 30 minutes with strong nitro-hydrochloric acid; if much action takes place, the solution should be decanted off, fresh acid poured on, and the ore digested for another 15 minutes. The solution is decanted through a filter-paper and the residue washed thoroughly by decantation; if the original ore contained wolfram, the residue will now show particles of yellow tungstic acid, which can be removed by digestion with ammonia solution. Any residue on the filter-paper is thoroughly washed, the paper burnt, and the ash mixed with the ore. The ore thus prepared is now ready for the assay proper. If the ore contained much arsenical or iron pyrites, it is advisable to roast it at a dull-red heat before treating it with acid; any magnetic minerals present may also be removed by means of a magnet; this is best done by the use of a horseshoe-shaped electro-magnet or a powerful permanent magnet, the poles being enclosed in a removable case of sheet brass; the magnet can be used with advantage when the ore is contained in a dish full of water, as, by agitating the magnet in this,

all the non-magnetic particles can be washed away from the magnetic ones.

In Cornwall the old Cornish process is still much used in spite of its admitted inaccuracy. One thousand grains of the ore are mixed thoroughly with 200 grains of ground anthracite, the mixture is transferred to a plumbago crucible, which is heated for 20 minutes in a very hot coke fire; the pot is then lifted out, the sides are scraped down with a pointed, charred stick of wood, the mass is well stirred with it, and the pot is replaced and heated again strongly for another 10 minutes. The pot is then taken out, allowed to cool somewhat, and the molten tin is poured into a flat bar ingot mould, holding back all the residue with a stick. The residue is then scraped out of the crucible and pounded down in an iron mortar, and all the carbonaceous matter is washed off in a dish; the remainder is dried and fused in a small clay crucible with a little carbonate of soda and poured; the button of tin thus obtained is added to the bar obtained in the first pouring, and both are weighed together.

The more accurate method, and the one more generally employed, is the potassium cyanide method; 100 grains of the ore, after being purified as completely as possible by the method already described, are mixed with 200 grains of roughly crushed potassium cyanide (the so-called gold cyanide, containing at least 98% KCy should be used) and 20 grains of finely ground charcoal; a layer of from 50 to 100 grains of potassium cyanide is placed at the bottom of a small clay crucible, and upon this the above mixture, which should about one-third fill the crucible. This is heated in a dull coke fire at a low red heat for about 25 minutes, until the contents of the crucible are in tranquil fusion; they are then poured, and the resulting button of tin is cleaned and weighed. Some assayers dispense with the charcoal, in which case a weight of potassic cyanide equal to five times the weight of the tinstone should be employed. The slag may be dissolved by boiling with

water, in order to see whether it contains any particles of disseminated tin; if the assay is properly conducted the amount of this latter is so small that it may be, and usually is, neglected. It is often practically impossible to remove the whole of the iron from the tinstone before running it down with potassic cyanide, and when this is the case, the button of tin is likely to contain iron. When accurate results are required, it is best to cut off a portion of the tin button, to dissolve it in hydrochloric acid in an atmosphere of carbonic acid, and to titrate the stannous chloride produced by a standard solution of ferric chloride, using a solution of ammonic sulphocyanate as an indicator.[1]

The quality of the tin produced may be tested roughly as follows: the buttons produced by fire assay are melted down in a graphite crucible in a coke fire at the lowest possible temperature. When they are melted, the pot is taken out of the fire and allowed to cool, skimming the surface of the molten tin with a charred stick, until the surface of the metal remains bright and no longer tarnishes by oxidation. The tin is then poured into a bar-shaped ingot mould, made of stone or marble, set quite level, and remaining undisturbed until the tin has set; all skimmings must be held back by means of the charred stick whilst the metal is being poured. The surface of pure tin should be smooth, bright, and somewhat convex; a rough surface indicates contamination with lead and a frosted surface with antimony. It need hardly be said that in important cases, or in dealing with a parcel of tinstone of unknown quality, it is preferable to supplement this rough test by a complete analysis of the tin buttons.

The assay of poor material is often made by panning down the crude material, after first crushing if necessary, and then assaying the heavy residue by the cyanide method. This method answers fairly well in most cases, if a con-

[1] The dry assay of tin ore by various methods has been critically examined in an admirable paper by H. O. Hofman. *Trans. Amer. Inst. Min. Eng.* XVIII. 1884. p. 3.

siderable quantity of material is panned in an ordinary gold pan, and the tailings are caught and panned two or three times over. In some cases, especially when dealing with fine tailings and slimes, the losses in panning are so heavy as to render the method impracticable. In such cases a chemical method must be employed, the principal difficulty in which consists in getting the tin into solution.

The ore may be fused with sulphur and potassic carbonate, producing a soluble potassic sulphostannate. This is dissolved out in water, and on the addition of dilute sulphuric acid to the filtered solution, stannic sulphide is precipitated, which may be roasted to oxide and weighed in the usual manner. This method is, however, more suitable for the accurate determination of the percentage of tin in a rich material than for the analysis of poor material. The latter is perhaps best treated by reduction; the substance is heated to full redness for three-quarters of an hour in a current of hydrogen or coal gas, whereby the tin is reduced to the metallic state; some chemists use zinc vapor for the same purpose. The reduced tin is dissolved in hydrochloric acid, and the tin is precipitated as sulphide by sulphuretted hydrogen from the solution, or it may be determined volumetrically.

Another method consists in fusing the ore in an iron or nickel crucible with about 20 times its weight of sodic hydrate, a little charcoal powder being also added when a nickel crucible is used. The fused mass is dissolved in hydrochloric acid, which converts the sodic stannate into stannic chloride; the latter is reduced to stannous chloride by placing strips or rods of iron in the acid solution, the reduction being usually complete in half an hour and any copper or antimony present being precipitated. The solution is filtered, again reduced completely, cooled down as rapidly as possible, and titrated with a standard solution of iodine in potassic iodide, using a starch solution as an indicator. Titration may also be performed by means of a standard solution of ferric chloride, the end of the reaction

being indicated either by the yellow color of the solution, due to the ferric chloride, or by using a solution of ammonic sulphocyanate.

In the absence of other reducing agents the stannous chloride in a solution may also be titrated by means of a standard solution of potassic bichromate, using potassic iodide and starch as an indicator.

In Cornwall it is customary to determine the percentage of tinstone or "black tin" in a poor material by vanning it on a vanning shovel; the results are often returned as pounds of black tin to the ton.

CHAPTER II

Principles of the Metallurgy of Tin

The metallurgy of tin is in so far comparatively simple, in that the smelter has but one ore to deal with, namely, stannic oxide or cassiterite, which is delivered to him in a state of comparative purity; this ore is in practice almost always reduced in the same way, namely, by contact with carbon or carbonaceous matter. It seems highly probable that in smelting with charcoal, cyanide of potassium may be produced by the combination of the alkalies present in the ash, the carbon of the fuel and atmospheric nitrogen, and that the alkaline cyanide thus produced may play a part in the reduction of the oxide of tin. The reactions involved are therefore of the simplest kind theoretically, but practically the process is complicated by the facts that:

(1) The temperature of reduction is so high that other metals, the oxides of which are invariably present in greater or smaller quantity, are reduced at the same time, and alloy with the reduced tin; this applies with especial force to iron.

(2) The tin ore must be contained in a furnace capable of resisting the high temperature required; hence the furnace lining must either be acid, consisting of silica or silicates, or basic, consisting of lime or magnesia. In the former case, which is the usual practice, a certain quantity of silicate of tin is produced; in the latter stannates would be formed. In both cases silico-stannates are probably also produced. Since nearly all ores contain some silicious matter, the former alternative is generally preferred.

(3) The slags produced are too rich in tin to be thrown away, and they require further treatment; part of the tin

is mechanically retained as intermingled prill, and this could be recovered by mechanical means, such as stamping and washing the slag. Since the greater portion of the tin present is however chemically combined as stannous silicate or as a silico-stannate, it is usually considered preferable to employ a smelting operation which reduces the latter tin at the same time that it allows the entangled tin to settle out. This reduction cannot be performed by means of carbon for reasons already indicated; an iron-reduction or substitution process is therefore employed, which produces a ferrous silicate and reduces the tin to the metallic state. The slag containing ferrous silicate is lighter than slag containing an equivalent quantity of tin, and at the same time is limpid and readily fusible, so that conditions are produced in this way that promote the separation of the tin and the production of clean slags. The iron is best added in the form of tin-iron alloys produced in the various operations of smelting and refining, and in an ideal tin-smelting process only just enough of these tin-iron by-products should be obtained to be re-absorbed in the corresponding slag-smelting operations.

There are therefore three stages that may be distinguished in the complete operation of tin-smelting: (*a*) Reduction or tin-smelting proper; (*b*) refining the impure tin; (*c*) cleaning the slags. Each of these stages may be performed in more than one way, and to their various combinations the different local modifications of tin-smelting are due.

Tin-smelting proper is conducted either in shaft furnaces or in reverberatories. The former method requires as an essential condition a supply of very pure non-flaming fuel — such as wood charcoal — in sufficient quantity and at a reasonable price, and is best suited to ores in not too fine a state of division and of a high degree of purity, therefore essentially to stream tin. The latter method requires fuel capable of giving a hot flame, and can be applied to less pure ores and to ore that has been very finely crushed;

it requires, however, a good supply of refractory material, and demands a higher degree of technical skill than the former process. Hence it is that smelting in shaft furnaces was the original process both on the Continent of Europe and in Cornwall, when charcoal and stream-tin ores were still abundant, and that it is still used very extensively throughout the far East, but has gradually given way in part on the Continent of Europe and in the East, and entirely in Great Britain, to reverberatory furnaces using coal as fuel, and capable of treating the finely crushed and more impure ores that necessarily result from lode mining.

The slags produced in either method contain tin both mechanically entangled and chemically combined as tin silicate, as stannates, and as silico-stannates. The former is separated either by a fusion that allows the molten tin to separate from the slag, or else by crushing and washing the slag. In both methods the greater specific gravity of the metal as compared with the slag is relied on for the purpose of separating it, but as tin is relatively a light metal, while the slags, which, as will be seen, consist largely of silicates of iron and at times of tin, are comparatively heavy, it becomes a very difficult matter to effect a good separation, and much of the metal remains with the slag, and is only recovered in the subsequent operation, the main object of which is to reduce the combined tin. This is usually done by smelting the slags at high temperatures, either in shaft or reverberatory furnaces, sometimes with the addition of strong bases, such as lime, or of iron, or the tin-iron alloys above referred to, or of bodies (such as oxide of iron) that will yield iron in the furnace. Generally this operation has to be repeated more than once, and the tin produced is much less pure than that obtained in the smelting process proper; it is in many places spoken of as "slag tin." This is the process of slag treatment proper, but in most methods of conducting the smelting process, the richer slags, together with any by-products rich in tin and free from injurious ingredients, are added to the ore-smelting charge.

Special methods of cleaning tin slags are also used, and will be subsequently described.

Tin may be refined by two different methods, both of which are employed in the case of impure metal; these methods are (1) "liquation," and (2) "boiling" or "tossing." In liquation advantage is taken of the low melting point of tin; impure tin is heated on the inclined bed of a furnace to a temperature but little above the melting point of tin; comparatively pure tin trickles down, and is received in a large basin or "float," in which it is kept in a molten state. The residue on the bed of the furnace consists of the difficultly fusible alloy of tin and iron known as "hardhead," which generally contains also sulphur, arsenic, copper, and other impurities. Liquation will obviously not remove readily fusible impurities such as lead and bismuth, and the tin is purified from these by boiling or tossing. The former operation consists in thrusting a billet of wood — applewood or cherry-wood being preferred — below the surface of the molten tin in the float; steam is given off together with permanent gases produced by the destructive distillation of the wood, and their evolution throws the tin into violent agitation, projecting portions of the metal which splash back into the float, so that a large surface of tin in the molten state is exposed to the oxidizing action of the atmosphere. In tossing, the same result is attained by taking out the molten tin by ladlefuls and pouring it back into the float from a height of two or three feet. By either method oxidation is promoted, and the impurities in the tin, together with a certain quantity of the tin itself, are oxidized and form a pulverulent scum on the surface of the float, whence they can be skimmed off from time to time. The metal is allowed to stand for some hours before it is finally ladled out and cast into moulds, so that the impure metal may settle down to the bottom of the float, tin being, as already stated, specifically lighter than most of the impurities that are apt to impair its valuable qualities. This fact was already known to Lazarus Ercker, who wrote in 1672.

Tin is invariably poured by this indirect method, *i.e.*, by ladling out of a float and not direct from the furnace, however pure it may be, because the temperature at which it is cast has a powerful influence upon the quality of the metal, and needs careful watching and regulating. If cast at too high or too low a temperature, it is apt to be brittle and its color and luster impaired.

The various tin-bearing products obtained in the refining operations are added to the furnace charges in ore or slag-smelting, according to circumstances, so that as little as possible of the metal contained in these various substances may be lost.

Wet methods and electrolytic methods of producing tin have been proposed from time to time, but none have yet attained any measures of success. Seeing that practically the sole ore of tin is cassiterite, which is distinguished by its chemical inertness, there seems little probability of any wet method of reduction being able to compete with the smelting processes.

CHAPTER III

Smelting in the Shaft Furnace

This furnace in its simplest form consists of a short vertical shaft, circular, square, or rectangular in cross section, and of moderate height. The fuel used is charcoal, which is charged in alternate layers with the ore; air is supplied by means of blast almost invariably cold, commonly forced in through from one to three tuyeres, which are usually not very high above the bottom of the crucible, and the reduced tin generally trickles continuously from a small tap-hole into a forehearth. One form of Chinese shaft furnace is, however, worked by natural draft. The exact nature of the chemical reactions is still doubtful. The ore may be reduced by the direct action of carbon in the zone of combustion, where the heat is ample, or partial reduction may take place higher up in the furnace, the reducing agents being possibly carbonic oxide, or hydrogen generated by the reaction of the glowing charcoal upon moisture in the air blown in. It seems probable to the writer, as already suggested, that cyanide of potassium is an active reducing agent in the cooler zones of the furnace; the fact that this salt is abundantly formed in the blast furnace is amply proved,* and it is quite possible that one of the advantages possessed by charcoal over coke in this process is due to the large amount of alkali in the ash of the former, which would tend to increase the amount of cyanide present in the furnace. The slag produced consists chiefly of silicates of iron and of the other bases present, together with titanates or tungstates in many cases, and invariably a certain amount, and often a great deal, of silicate of tin or of

* John Percy: *Metallurgy of Iron and Steel*, 1864, p. 447.

silico-stannates. Since ores in a high state of purity are generally worked in this furnace, the proportion of slag to metal is small; the production of silicate of tin is necessary to prevent most of the impurities that might deteriorate the quality of the metal from passing into the latter. As long as the slag contains a notable quantity of tin silicate, the reduction of metallic iron is prevented, because any iron that might be reduced would, as already pointed out, reduce the silicate of tin with the formation of metallic tin and silicate of iron. Generally speaking, the slags produced in the shaft furnace have to be subsequently retreated, whereby an impure tin is obtained from them, the tin produced in the smelting process proper being at times sufficiently pure to need no refining. While the principles here enunciated hold good in all cases, it becomes necessary to distinguish a considerable number of different processes, all of which are local variations of the above general method.

The Old Cornish Process. — Pryce * states that the reverberatory furnace was introduced into Cornwall for tin-smelting with fossil fuel in the commencement of the reign of Queen Anne (about 1705), and that up to that time the shaft furnace, known as the blowing-house, with charcoal as fuel, was always employed. He has, however, reason to believe that the original method of smelting in Roman or pre-Roman times was "to dig a hole in the ground, and throw the tin ore on a charcoal fire, which probably was excited by a bellows." Nothing is known as to the period when this primitive device was replaced by some form of the built-up shaft furnace, which maintained its place for so long a period. We shall, however, find ample evidence that such a primitive method, about which Pryce seems to have known nothing whatever, was the original method used in the far East.

The Cornish tin-miner or tinner took his cleaned stream tin to the blowing-house,† "paying the owner of the house

* Pryce: *Mineralogia Cornubiensis*, 1778, p. 282

† *Ibid.*, p. 136.

twenty shillings for every tide or twelve hours, for which the blower was obliged to deliver to the Tinner, at the ensuing coinage, one hundred pounds gross weight of white Tin for every three feet or one hundred and eighty pounds of Stream Tin so blown; which is equal to fourteen pounds of Metal for twenty of Mineral, clear of all expense."

Pryce describes the smelting process as follows: "The furnace itself for blowing the Tin is called the Castle on account of its strength, being of massive stones cramped together with Iron to endure the united force of fire and air. This fire is made with charcoal excited by two large bellows, which are worked by a water-wheel, the same as at the iron forges. They are about eight feet long and two and a half wide at the broadest part. The fire-place, or castle, is about six feet perpendicular, two feet wide in the top part each way, and about fourteen inches in the bottom, all made of moorstone (*i.e.*, granite) and clay, well cemented and cramped together. The pipe or nose of each bellows is fixed ten inches high from the bottom of the castle, in a large piece of wrought Iron, called the Hearth-Eye. The Tin and charcoal are laid in the castle, *stratum super stratum,* in such quantities as are thought proper; so that from eight to twelve hundredweight of tin, by the consumption of eighteen to twenty-four sixty-gallon packs of charcoal, may be melted in a tide or twelve hours' time. Those bellows are not only useful for igniting the charcoal, but they throw a steady and powerful air into the castle, which, at the same time that it smelts the Tin, forces it out also through a hole at the bottom of the castle, about four inches high and one and one-half inches wide, into a moorstone trough six and one-half feet high and one foot wide, called the float; whence it is ladled into lesser troughs or moulds each of which contains about three hundred pounds of Metal, called Slabs, Blocks, or Pieces of Tin, in which size and form it is sold in every market in Europe; and on account of its superior quality is known by the name of Grain Tin, which brought a price formerly of seven shillings, that is further advanced,

the last two or three years, to ten or twelve shillings per hundred more than Mine Tin is sold for, because it is smelted from a pure Mineral by a charcoal fire; whereas Mine Tin is usually corrupted with some portion of Mundick, and other Minerals, and is always smelted with a bituminous fire, which communicates a harsh, sulphureous, injurious quality to the Metal."

The general appearance of these old castles may be gathered from Fig. 5, reproduced from Karsten's *System der Metallurgie*, published in 1832.

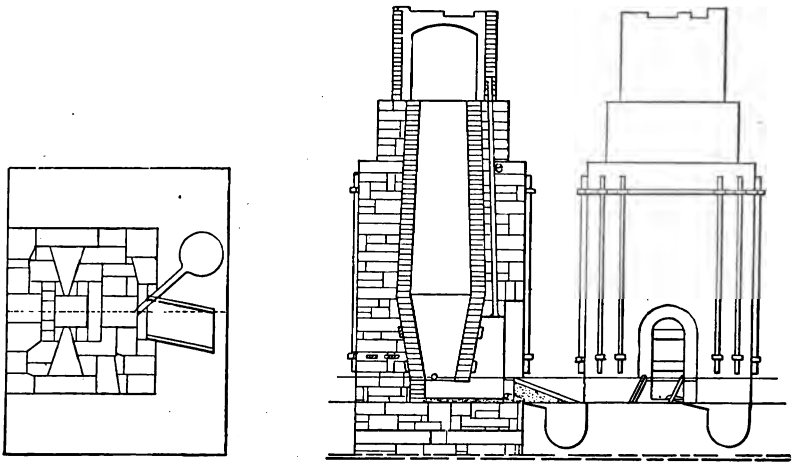


FIG. 5. — Cornish tin castle; plan, vertical section and front elevation

The above description has been quoted *in extenso*, because it not only conveys a good idea of the process as carried on in Cornwall more than a century ago, when the shaft furnace and the reverberatory were working side by side, but mainly because it may also be taken as a typical account of the process as conducted in other parts of the world. It is noteworthy that the above quotation seems to compel the inference that "grain" tin is so called, not, as is generally supposed, because the hot ingots readily break up into columnar grains, but because the metal was smelted from stream tin which occurs in grains, in

contradistinction to that produced from ore from the mine. The stream tin must have been well cleaned, as it appears to have yielded at least 70% of metal; moreover, Pryce makes no mention of any process of refining, nor does he refer to any treatment of the slag, though he describes both in his account of smelting in the reverberatory furnace. It seems from the above figures that each shaft furnace was capable of producing about 15 cwt. of metallic tin per 24 hours with a consumption on an average of 315 bushels of charcoal, which, if of hard wood, as seems likely, may have weighed about 48 cwt., the cost to the tinner being about 27*s*. per ton. The value of tin at that time was about £60 per ton.

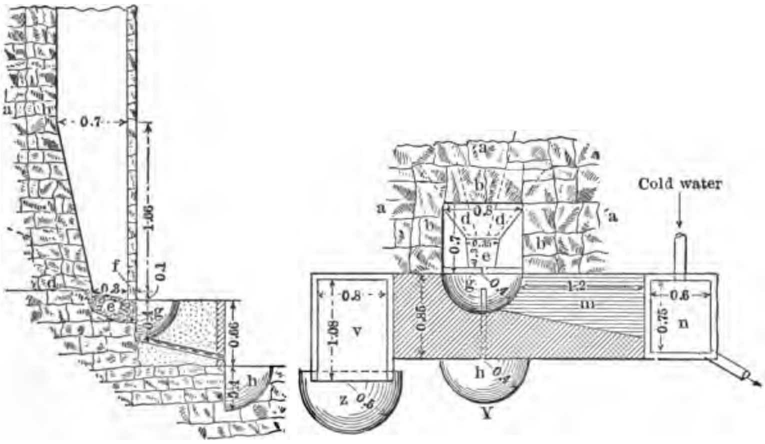
The German Process. — As appears from all that can be gathered from the older writers, such as Agricola and Ercker, the shaft furnace used in early times for smelting stream tin did not differ materially from that in use to-day for smelting the concentrates produced by dressing the ores obtained from the granitic district of the Erzgebirge, both on the Saxon and on the Bohemian sides of the mountain range.

Plattner * describes the method of tin-smelting, as carried on at Altenberg about the year 1850. The dressed ore is roasted, and, if it contains bismuth, treated with dilute hydrochloric acid in wooden vats, the quantity of acid used being 6% of the weight of the ore. The ore is then again washed, when it will contain 50 to 60% of tin. It is smelted in a shaft furnace 15 feet high and trapezoidal in internal cross-section, the width from front to back walls (which are parallel throughout) being about 26 inches, and the length of the back wall 18 inches at the tuyere level and 26 inches at the throat, while that of the front wall is 12 inches at the former and 20 inches at the latter level. The bottom of the hearth consists of a block of granite or porphyry, having a slope of 4 inches towards the front; there is a forehearth

* *Vorlesungen über Allgemeine Hüttenkunde,* by C. F. Plattner, Vol. II, p. 33.

cut out of charcoal brasque, in front of which a kettle is set. The furnace smelts in 24 hours 30 to 36 cwt. of tin ore, to which one-fourth of its weight of slag is added; the production is about 15 cwt. of tin, the charcoal consumption being at the rate of 1½ baskets of 12 cubic feet capacity, or altogether 18 cubic feet or about 210 lbs. of charcoal per cwt. of tin. At the end of a campaign the slags are re-smelted in a furnace similar in shape but only 9 feet high, somewhat larger in cross-section, and having a bottom made of charcoal brasque.

The furnace in use to-day in Saxony * is very similar to the above; it is shown in vertical section and in plan in Figs. 6 and 7, while Figs. 8 and 9 (after Kerl) show what it was



FIGS. 6 and 7. — Modern Saxon Blast Furnace

like at the beginning of the century, the changes being almost inappreciable. The furnace proper consists of three walls of granite, *b*, protected by a massive outer walling of gneiss or granite, *a*. The front wall *c* is made light, so that it can easily be torn down and renewed when repairs are

* This description of Saxon tin-smelting is the result of a comparison of the older German metallurgical writers, chiefly Kerl and Plattner, supplemented by information as to the modern practice from Mr. Albert Doerr, of Freiberg, to whom I am indebted for much useful information on the subject. — H. L.

necessary. At *d* is the tuyere-arch, through which two tuyeres are inserted. The furnace bottom *e* consists of a

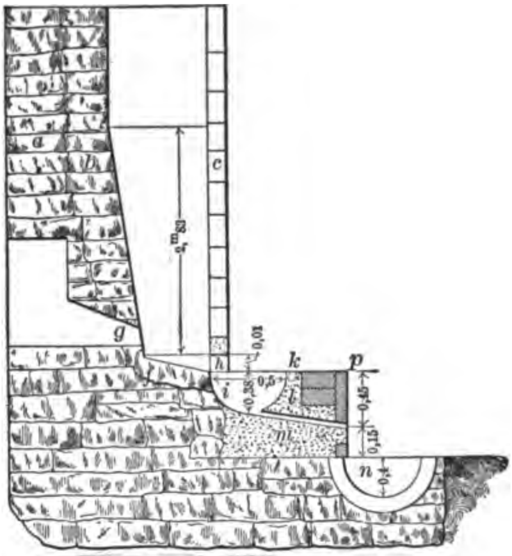


FIG. 8.—Vertical Section of Saxon Blast Furnace

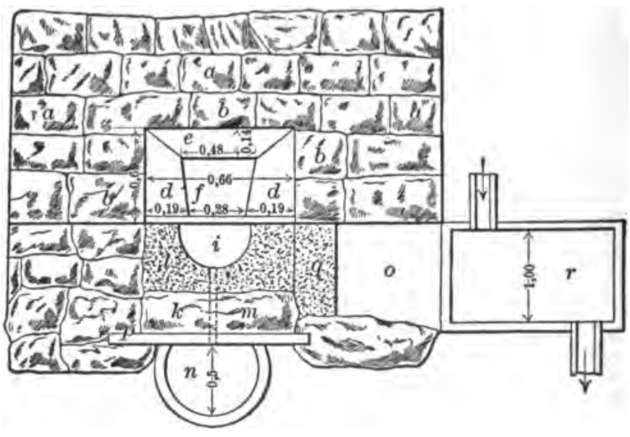


FIG. 9.—Plan of Saxon Blast Furnace

single block of granite. The tap-hole *f* is always left open, and through it tin and slag flow continuously into the fixed

forehearth *g*, which is cut out in a mixture of charcoal breeze and clay held in place by blocks of stone and an iron plate, as shown in the drawings. In this forehearth the metal collects beneath a layer of slag. The latter is allowed to flow or is drawn over the plate *m* into the tank *n* filled with water, the object being to make it thereby more brittle, so as to enable it to be readily crushed. The tin is allowed to accumulate, and is tapped off at intervals of from 8 to 12 hours through the forehearth tap-hole into the float *h*. Above the furnace there is a hood, not shown in the drawings, communicating with a series of dust chambers in which any fumes escaping from the furnace, and more especially any fine ore carried up by the blast, are caught and collected.

The furnace used at Altenberg is about 9 feet 6 inches high. Blast is furnished by means of a pair of large bellows worked by a water-wheel. Each bellows is worked at an average rate of 12 strokes per minute, the total amount of air thus injected into the furnace being about 680 cubic feet per minute. The blast is delivered through two sheet-iron tuyere-pipes of about $1\frac{3}{4}$ inches diameter, made of light sheet iron; these two tuyere-pipes discharge into what may be called the tuyere proper, being simply an aperture in the rear wall of the furnace situated some 4 inches above the furnace bottom; the tuyere-pipes are not clayed in nor made tight in any way, and are placed almost horizontal. The furnace and forehearth are well heated as a preliminary operation; the former is next filled with charcoal, which is ignited and the blast then turned on. Charges of about 100 pounds each, consisting of about two-thirds concentrated ore and one-third slag, are put on every 15 or 20 minutes, enough charcoal being added between each charge to keep the furnace full to the top; the charcoal is always damped before being charged, and water is sprinkled at intervals upon the charge in the furnace; the object is to keep the top cool and to prevent, as far as possible, the finer particles of ore from being carried off by the current of air. Care is taken to

keep the temperature down; the tin, as it runs from the furnace, should be reddish in color, the fumes coming out of the tap-hole should be bluish, and the interior of the furnace as seen through the tuyeres should be yellowish. If the latter appears white hot, the temperature is too high, and the blast must be reduced, while thick heavy fumes and a sluggish flow of tin and slag denote the opposite condition. As the tin cools down somewhat in the forehearth, a quantity of hardhead separates out; this hardhead used to be re-smelted, but now appears to be sold to works at Tostedt, near Hamburg, where it is worked up with other tin-bearing materials.

The ores treated consist of concentrated lode-stuff, containing 60 to 65% of metallic tin, and a furnace charge is composed of this ore together with 25 to 50% (usually about 30%) of slags from a previous operation and 6 to 7% of hardhead, skimmings, and other tin-bearing products. The average capacity of the furnace is 3,200 pounds of ore and up to 1,600 pounds of slags in 24 hours, but varies greatly with the quality of the ore as received from the dressing floors; at present the furnace yields 900 to 1,200 pounds of tin in 24 hours, the fuel consumption being about 1,800 pounds of charcoal per ton of tin produced. The loss of metal is very great; it is said by Lampadius to reach 15%, 8 to 9% being due to volatilization. Two men per shift are needed to each furnace. As now worked, a smelting campaign lasts only some 36 hours, and these are separated by intervals of about three weeks, so that the industry is by no means in a flourishing condition.

The products of the smelting operation are metal, slags, and hardhead, which latter forms sows either in the crucible of the furnace or in the forehearth as above mentioned. The tin produced is impure, containing 94 to 97% of Tin, the chief impurities being Copper, Iron, and Arsenic. The following table shows the composition of two typical hardheads from Altenberg, I being an analysis by Berthier and II by Plattner.

Number	Sn	Fe	W	Cu	C	Total	Approx. Formula
	%	%	%	%	%	%	
I............	32.22	64.14	1.64	—	—	98.00	Fe_4Sn
II............	80.89	17.16	—	0.99	0.96	100.00	$FeSn_2$

The slags come from the furnace in two conditions, rich and poor; the former contains unreduced ore and is returned to the furnace with the ore. The latter undergoes a special subsequent treatment. The following are analyses of such slags from Altenberg, by Lampadius and Berthier respectively:

Number	SiO_2	SnO_2	WO_3	FeO	MnO	CaO	MgO	Al_2O_3	Total
	%	%	%	%	%	%	%	%	%
I	20.05	25.12	—	30.15	—	1.10	1.23	5.00	82.65
II	16.00	32.00	1.00	41.00	1.70	3.70	1.70	2.40	99.50

These slags also at times contain so much metallic tin in small prills that they are subjected to crushing and washing; or else they are re-smelted directly with higher blast pressure in the ore-smelting furnace, which is only kept on ore for two or three days at a time at best. They are smelted together with other tin-bearing residues, the products being slag-tin and a slag that often contains a good deal of metal and has to be crushed and washed. The slag-tin thus produced is generally quite as pure as the tin from the ore furnace. The slags produced contain about 10 or 12% of SnO_2 and are re-smelted generally in furnaces similar to the ore furnaces, but having two tap-holes and being only about 6 feet high, to obviate as far as possible the reduction of iron. The slags thus produced, which generally contain 5 to 7% of SnO_2, are re-smelted once or twice more, being finally thrown away when they contain some 3% of SnO_2.

The tin that collects in the float of the furnace is at once refined without allowing it to cool. This operation is per-

formed by ladling it out and letting it run slowly over an inclined corrugated cast-iron plate (*v*, Fig. 7) about 3 feet 6 inches long, 2 feet 6 inches wide, and 1.5 inches thick, sloping about 1 in 7 to 1 in 10, upon which there is a layer some 6 inches deep of red-hot charcoal; the charcoal acts as a filter, retaining the less fusible impurities, while the purified tin trickles through the charcoal and collects under a layer of red-hot charcoal in a float (*z*, Fig. 7) at the lower end of the plate; the residual hardhead is freed from adhering tin as far as possible by beating it with wooden mallets, and is added to the charge in the first slag-smelting. The molten tin is allowed to cool down in the float until it has reached the right temperature for casting, when it is ladled out into moulds or slabs, or poured onto a copper plate, after which it is hammered up into rounded balls.

The following analyses will give an idea of the changes produced in the metal by these operations of refining:*

Unrefined Tin

Tin	94.5 to 95.3%
Copper	2.5 to 3.6%
Iron	0.7 to 1.9%

Liquation residues (hardhead from liquating plate):

Tin	59.09%
Iron	9.24%
Tungsten	3.35%
Copper	11.80%
Silica and slag	8.47%
Intermixed carbon and oxygen combined with the metals	8.05%
Total	100%

Saxon rolled tin:

Tin	99.76%
Iron	0.04%
Arsenic,	trace
Total	99.80%

* *Berg- und Hüttenmännisches Jahrbuch der K. K. Bergakademie Wien*, Vol. XIII, 1864: A. Löwe (1842).

Saxon rod tin:

Tin	99.93%
Iron	0.06%
Arsenic,	trace
Total	99.99%

The production of tin by these methods has now shrunk to very small dimensions; in 1894 * there were only two mines in Saxony producing tin ore, the total quantity of dressed tinstone being 84 tons; of this amount 82.35 tons were produced at Altenberg, which yielded on smelting 51 tons of tin and 3,300 pounds of hardhead. In 1895 the production is said to have been only 35 tons of tin and 2 tons of hardhead. Since then the production has continued to remain insignificant, the average production of dressed tin ore and concentrates being only about 100 tons yearly from 1900 to 1908. Small quantities of imported tin ore, chiefly from Bolivia, are smelted together with the native ore.

In Bohemia, at the chief centers, Graupen and Schlaggenwald, the process is practically identical. The ores there are dressed, forming two grades, coarse ore containing about 70% of tin, and concentrates containing 45 to 48%. These are smelted with the addition of about 25% of slags from a previous operation and sometimes of imported (Bolivian) ores. About 2,300 pounds of ore are smelted in 24 hours with a consumption of 350 cubic feet of charcoal; the average yield of tin from the above charge would be 1,000 pounds.

The Bohemian smelting furnace is also trapezoidal in section and about 9 feet high; the front and back walls are vertical, the side walls slightly flaring. The furnace is built of brick, the bottom being made of fine-grained sandstone; it has one tuyere. The furnace products are similar to those obtained in Saxony and their treatment is practically identical, the slags being resmelted several times, and crushed and washed if necessary; as soon as an ore-smelting

* *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen*, 1895, p. 47.

campaign, which lasts from three to five days, is finished, slag-smelting begins. The following is an analysis by Von Lill* of Schlaggenwald tin slag produced in the first smelting of the ore slag:

SiO_2	24.06%
WO_3	24.33%
SNO_2	10.41%
FeO	20.75%
MnO	5.64%
Al_2O_3	9.00%
CuO	3.50%
MgO	0.37%
Total	98.06%

The composition of some samples of Bohemian tin is shown by the following analyses:

Samples of Tin	Tin	Copper	Iron	Sulphur	Arsenic	Total
	%	%	%	%	%	%
Schlaggenwald unrefined tin ...	97.339	2.726	0.684	Trace	Trace	100.749
Schlaggenwald rolled tin	98.660	1.360	0.060	—	Trace	100.080
Schlaggenwald fine tin	99.594	0.406	—	—	—	100.000

In the year 1894 there was only one mine and smelting works in operation at Graupen in Bohemia;† the native ores treated were only 24 tons, but 101.2 tons of tin ore and 16.4 tons of crude tin from Bolivia were also smelted, the total output of metallic tin being 80.2 tons. As far as can be gathered from the figures given, only about 3 tons of this output were the product of the native ores. From that time to the present (1908) but little variation is to be noted; the annual production of metallic tin is between 20 and 25 tons, less than half of this being apparently derived from native, and the remainder from imported ores.

At Freiberg, in cupelling base bullion containing some tin, a certain amount of skimmings is produced in the first

* *Berg. u. Hütt. Jahrbuck d. K. K. Bergakademie Wien.* Vol. XIII, p. 64.

† *Statistisches Jahrbuch des K. K. Ackerbau Ministeriums für* 1894, Vol. II, Part I, p. 72.

stage of the operation, which contain all the tin as oxide together with litharge, oxides of arsenic and antimony, and some silver; this product is first desilverized and the residues containing about 12% of tin are smelted in small shaft furnaces; the metal so produced is calcined, producing antimonial lead and oxides of lead and tin still very impure. By a series of alternate reductions in shaft furnaces and calcinations of the product, an alloy of tin, lead, and antimony, containing about 33% of tin, ultimately results, which is sold in this condition; the quantity thus produced is quite unimportant.

At Pitkäranta,* in Finland, a little tin ore used to be mined, which was smelted in a manner similar to that used in Saxony, a variation of the German method being employed. The ore is practically free from sulphurets, and is dressed in the usual way on shaking-tables and round buddles. Some of the copper ores raised here contain a certain amount of tinstone; such ore is first treated for copper in the wet way, and the residues are then submitted to concentration, the concentrates obtained being smelted with the others. Most of the tin ore is obtained from the No. 4 Omeljanov mine, and is of fairly high grade, the dressed ore containing 55 to 65% of tin. The furnace used is a cylindrical shaft furnace, 10 feet in height and 18 inches in inside diameter; the fuel used is charcoal. The tin is run into bars, and these are refined by being placed upon a layer of red-hot charcoal contained in an inclined iron cylinder; the purest metal, which liquates through first, is cast into small ingots weighing about 25 pounds, of about the same shape as ordinary copper ingots. Another portion of the tin is cast into rods about 18 inches long. The following is an analysis of the refined metal:

Sn	99.74%
Cu	0.08%
Fe, Pb	0.18%
Total	100%

* Private communication to the author from Dr. K. A. Moberg, of Helsingfors.

The slag produced in the ore-smelting is very rich, as shown by the following analysis: Mechanically enclosed tin, 8.33%; Sn (as oxide), 56.19%; Fe (as oxide), 11.96%; silica and other constituents undetermined. These slags are re-smelted together with other by-products; the slags thus produced are run out into conical moulds and allowed to set, the tin collecting in the apex of the cone; this portion is broken off when cold and refined, the rest being looked upon as worthless.

The tin production of Pitkäranta * has been small and variable, as shown by the following table:

Product	1891	1892	1893	1894	1895
	Metric tons	Metric tons	Metric tons	Metric tons	Metric tons
Dressed tin ore	18.42	25.70	21.33	13.18	54.00
Tin	9.60	9.79	6.80	3.93	20.78

The total production from 1874 to 1895 inclusive was 150.4 tons of metal, or an average of 12.5 tons per annum. From that period onward it continued to decline until the mines were closed down in 1900.

Oriental Methods of Tin Smelting. — It seems probable that the Chinese method of smelting was first introduced into the Malay Archipelago, probably at Banka, and that from there it extended into the Malay Peninsula, displacing probably in both places cruder native methods. The original methods of the Chinese have subsequently undergone considerable modification, but it would seem that the change has been least in some of the more remote parts of the Malay Peninsula. It is stated by Van Diest † that the natives first worked tin in Borneo about the year 1700, and that the Chinese made their way into the island in the latter half of the eighteenth century. The natives of the island used to smelt their tin in the same way as they had been

* *Bidrag till Finlands Officiela Statistik,* XVIII, "Industrie Statistik."

† *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indie,* 1872, I; Introduction, p. 27; "Het Tin Smelten op Bangka," *ibid.*, p. 217.

accustomed to smelt iron, for which metal the Malay Archipelago has long been famous. They dug a shallow pit about 1 foot in diameter at the top; ignited charcoal was thrown in and then small quantities of charcoal and ore, and a high temperature was obtained by a blast which was conveyed to the bottom of the pit by a couple of bamboo pipes passing through the ground. The blast was produced by means of a piston working in a vertical hollow tree-stem, into the lower end of which the bamboo tubes opened. The natives do not seem to have attempted to treat their slags, which have been found in several places in the island, *e.g.*, near the village of Kepodarat, in the district of Toboali, where they were found to contain 15% of unreduced tin oxide, in addition to prills of tin.

This primitive process may be better understood from a description of it, as carried on in recent times in Siak, Sumatra,* which at one time produced a great deal of tin, though it is now no longer a producer. At Kota-rena the natives smelted the ore in a furnace made by digging a hole in the clayey ground to a depth of about 20 inches and with a diameter of 14 inches at the mouth. The blowing apparatus consisted of two vertical hollow logs of wood, about 6 feet 6 inches high and 8 inches in diameter; in each was a piston, the two being worked alternately by one man, and from the bottom of each a bamboo tube conveyed the blast into the furnace. The smelting operation lasted 4 to 5 hours, three men being needed, namely, one smelter and two assistants, who relieved each other at the blower; the result of the campaign was from 24 to 26 pounds of metallic tin. The molten metal collected in the bottom of the hole and was cast into moulds made of pieces of split bamboo about 18 inches long, stopped with clay at both ends. The semi-cylindrical pieces of tin thus obtained weighed about 6 kati (8 pounds). The yield of metal appeared to be about 60% of the ore. Most of the tin thus produced was for

* *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indie*, 1874, I, p. 101: R. Everwijn, "Verslag van eene Onderzoekingereis in het Rijk van Siak."

consumption in the country itself; it was said to cost more to produce in these furnaces than in the usual Chinese furnace.

A very similar method practised by the Japanese may also be referred to here, which has been fully described by Prof. W. Gowland, F.R.S.* The furnace,† Fig. 10, was a

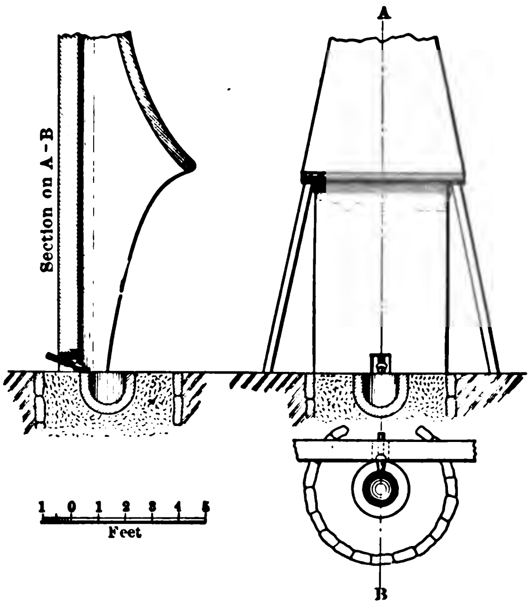


FIG. 10.—Japanese Smelting Furnace

shallow hole in the ground about 18 inches in diameter and 18 inches deep; to construct this an excavation about 4 feet by 4 feet and 2 feet deep is made, and filled with dry clay well beaten down; in the center of this bed of clay the shallow conical cavity is scooped out and lined for about 3 inches in thickness with a mixture of damp clay mixed with broken charcoal. The blast is supplied by two horizontal wooden bellows (very like those subsequently described, used by the Chinese), each blowing into a tube of bamboo terminating in a long clay nozzle, the latter resting on the edge of

* *Archæologia*, Vol. LVI, 1899, p. 267. † *Ibid.*, p. 277.

the cavity; a wall of wattle work covered with clay is erected to protect the bellows, and the men working them, from the fire. After the cavity has been dried, it is filled with charcoal, which is then lit; when it is thoroughly ignited, a layer of fresh charcoal is put on, then a layer of moistened ore, then another layer of charcoal, and so on, until a conical heap of charcoal and ore covers the furnace. The bellows are then worked vigorously until the entire heap sinks into the furnace cavity; the unburnt charcoal and slag are next raked off with a wooden rake, and the tin is ladled into long narrow clay moulds. The yield of each smelting charge is only about 30 pounds of metal, much being lost by volatilization and in the slag.

A somewhat similar furnace is still used in China proper, as shown by the description of tin smelting at Kotieou, in the province of Yunnan, recently published by W. F. Collins;* the furnace is shown in Fig. 11; there are 29 of these furnaces at Kotieou, and the output of a furnace is from 12 to 15 slabs, each weighing 1.1 picul (147 lbs.), per 24 hours; the furnaces are idle about 8 months in the year, and are in full work only during November, December, and January. The furnaces are built of brick, made on the spot, the blast being produced by the usual horizontal Chinese blowing-cylinders worked by hand. Each furnace is worked by 10 men in two gangs of 5 each, with a foreman, who work alternate six-hour shifts. The slags are pounded, worked, and re-smelted until considered clean; the tin is not refined and contains some iron and lead. The output of tin in the province of Yunnan is about 4,000 tons per annum.

Tin is also smelted in the same primitive Chinese furnaces in Tonkin in the district of Kao-Bang, near the Chinese frontier; the ore is the usual form of stanniferous gravel, well developed in the Tinh-Tuc valley. It is washed as usual in sluice-boxes, and the washed ore is smelted in small blast furnaces; owing to its impurity,

* *Trans. Inst. Min. Met.*, Vol. XIX, 1909–10, p. 192.

the output per furnace is but small. The ore contains on an average about 50% of tin and yields about 40% in the furnace. The smelted tin is cast in blocks of about ½ cwt. each.*

It is interesting to compare the above descriptions with that given by Dr. John Percy † of iron smelting in Borneo,

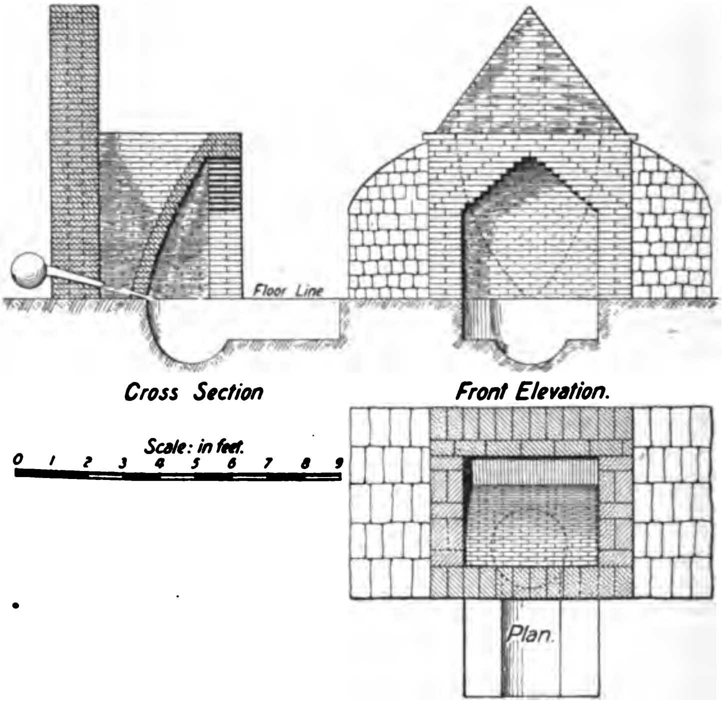


FIG. 11. — Chinese Tin-smelting Furnace, Kotieou, Yunnan, China

and also to note the strong resemblance between these processes and the method stated by Pryce to have been that probably used originally in Cornwall.

The original Malay smelting process, as practised up to about 1870 in Perak, where it may possibly have been learned from the Siamese, seems to be a slight advance on the

* H. Charpentier, "Le Développement Industriel et Minier du Tonkin." *Bulletin de la Société Industrielle du Nord de la France.* 1905.

† *Iron and Steel,* 1864, p. 273.

methods just described; as far as can be gathered it seems to have developed on the same lines as the native methods of iron-smelting that are stated to have been in use in and about the Siamo-Malayan province of Singgora. The furnace seems to have been a low clay cylinder, and the blast to have been produced by a crude blowing machine made of bamboos standing on end. The tin was ladled out into moulds making slabs about 2 kati ($2\frac{2}{3}$ pounds) in weight.

All these primitive methods have been displaced by the Chinese method, which itself shows many minor variations.

Though an interruption to strict chronological sequence, it may be convenient to give next a description of the crude Chinese methods as still practised in various parts of the Malay Peninsula, returning subsequently to the process as successively elaborated, and as now carried out in Banka and Billiton; it is really only in Banka, under the auspices of the Dutch government, that these processes have been at all exhaustively studied.

The furnaces used in the different districts of the Malay Peninsula vary somewhat in detail of construction, in dimensions, and in shape, depending upon the quality of the ore and the charcoal available, and apparently also on the fancy of the smelter. There are, strictly speaking, two methods or two variations of the general process in use in the Malay Peninsula, the first using an air furnace (*i.e.*, a shaft furnace, worked by natural draft without blast), and the second a blast furnace. The air furnace, called "Tonga" by the Chinese, can only be used when very good dense charcoal, such as that of the kompas tree, is available; in such cases it is preferred because it is said to make better tin, besides dispensing with the labor of blowing. In most of the tin-mining districts all kompas trees within a practicable distance have long ago been cut down, and the air furnace has therefore been perforce abandoned. In spite of somewhat extensive travels in the Peninsula, the writer has but rarely seen the air furnace in use, one of the few localities being the district of Tras, in the heart of the mountain range that

separates Pahang from Selangor; the tinstone in this district lies in very shallow gravel, is coarse and extremely pure. The air furnace is illustrated in Fig. 11, which shows the details of its very simple construction as seen when not in operation; when it is being worked, two clay tubes about

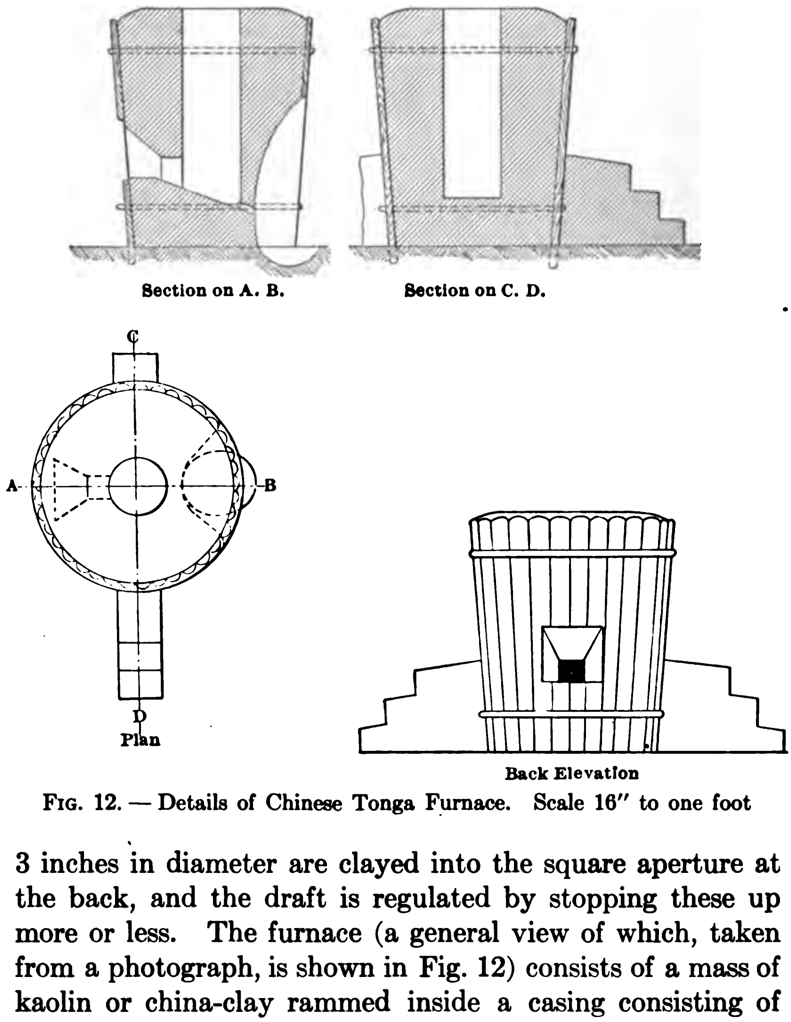


Fig. 12. — Details of Chinese Tonga Furnace. Scale 16″ to one foot

3 inches in diameter are clayed into the square aperture at the back, and the draft is regulated by stopping these up more or less. The furnace (a general view of which, taken from a photograph, is shown in Fig. 12) consists of a mass of kaolin or china-clay rammed inside a casing consisting of bamboos or poles stuck into the ground and held together by hoops of stout rattan; hoop iron may exceptionally be

used, as near Kuala Lumpor, Selangor. After the furnace has been built it is allowed to dry for some months; when sufficient tin ore has accumulated, a fire is lighted in the furnace and some charcoal is thrown in; the shaft is then filled with alternate layers of charcoal and tin ore, the charcoal being thrown on by basketfuls, each basket being about 2 feet in diameter and 2 feet high, while tin ore is thrown on

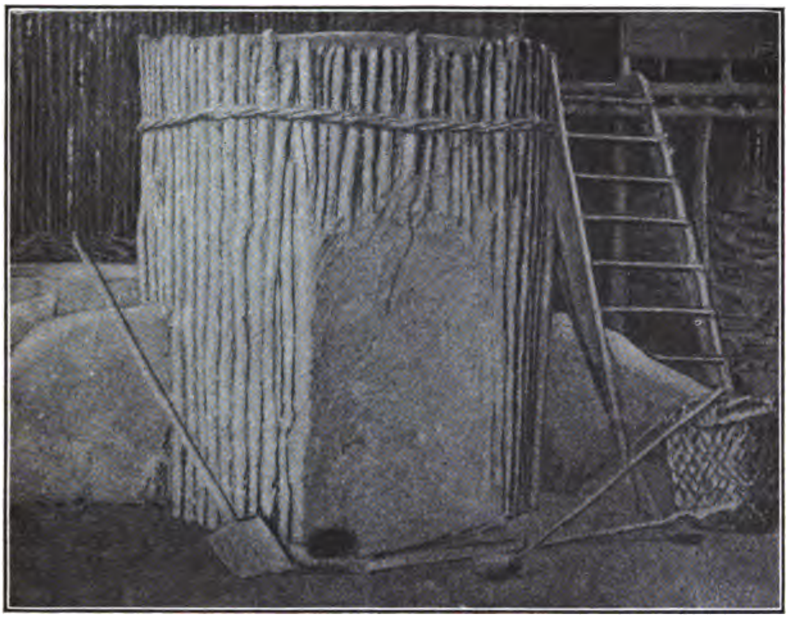
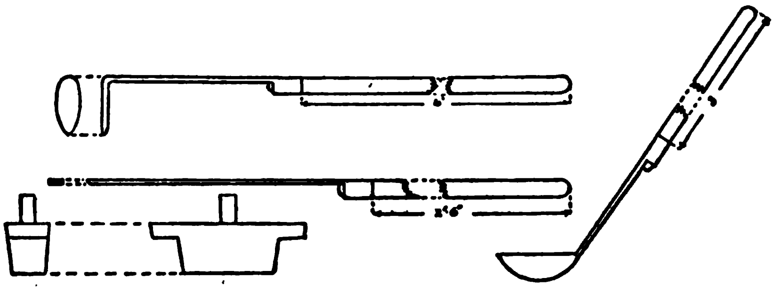


FIG. 13. — View of Tonga Furnace

by means of a square-mouthed shovel. The ore is damped from time to time, both to prevent the furnace-top from becoming too hot and to prevent the ore from being carried off by the draft. The tin soon conmences to trickle out of the tap-hole and to collect in the float, which consists of a cavity hollowed out in the ground in front of the furnace and lined with china-clay beaten smooth. This float is kept filled with red-hot charcoal; a little slag runs out from time to time, and is drawn off in irregular crusts by means of the

slag-rake shown in Fig. 14, the tap-hole being kept open by means of constant poking with the pricker (Fig. 15); a thin sapling is sometimes used in place of the latter. When sufficient tin has been collected it is ladled out by means of an iron ladle (Fig. 16), and is cast in sand moulds, these being made by stamping the wooden pattern shown in Fig. 17 into a small bed of sand that is kept close to the furnace for this purpose. The size of the ingot cast varies somewhat in different districts. In Tras the ingots run seven to the bhara,*



SCALE ¾ INCH = 1 FOOT.

FIG. 14, 15, 16 and 17.—Tools used by Chinese Tin-smelters, Malay Peninsula

or about 76 pounds each, and each furnace produces about 20 slabs in 24 hours, or say 1,500 pounds of metal. The ore, which is not always very well washed, yields 64 to 65 % of metal; its average assay is probably not far short of 70% of metallic tin. The consumption of charcoal is about 4 picul by weight for every 3 picul of tin produced, or approximately a weight equal to that of the ore smelted. The charcoal is here worth $1 to $1.50 per picul (say about 35 to 50 cents United States currency per 100 pounds of ore smelted). There

* The weights used by the Chinese in the Malay Peninsula are as follows: 1 bhara equals 3 picul; 1 picul equals 100 kati; 1 kati equals 16 tael. The normal picul weighs 133.33 lbs. avoirdupois, but there are many local differences; *e.g.*, in Tras and the whole of the Hulu Pahang the picul used for weighing bar tin is one-third heavier than the standard picul.

The dollar here referred to is the Mexican trade dollar, worth at date of writing these notes (1895) about 22 pence or 44 cents United States currency.

are generally two or three men employed about the furnace, in addition to those carrying in charcoal or ore and carrying out the slabs of tin. The slag as produced is examined by the smelter; if it carries unreduced ore, it is at once thrown into the furnace again with the ore charge; if not, it is kept for retreatment; it is stamped in foot-mills (which will be described further on) and washed to recover prills of metal, and is then smelted again after all the ore has been treated, or at any other suitable opportunity; the slag thus produced is again stamped, washed, and smelted. It is then as clean as the ore smelters can make it; in Tras nothing further seems to be done with it, because the district is so inaccessible that the cost of carriage, which can be performed only on men's shoulders, is practically prohibitive. When this district is opened up by roads, this slag will probably, as in other places, be sold to the slag smelters, of whom there are several near Kuala Lumpor (the capital and center of the tin-mining industry of Selangor) as well as in the other tin-mining centers of the Peninsula. A rough analysis by the writer of a sample of the first slag showed it to contain about 30% of tin (as metal and as oxide), silica, titanic acid, and protoxide of iron as the chief constitutents; no tungstic acid could be detected.

The air furnace is used whenever possible; thus it is (or was in 1892) in use at Sungei Besi in Selangor, although suitable kompas-wood charcoal cost $2.80 per picul as against ordinary charcoal at about 80 cents per picul. In this furnace the output was about 30 slabs per day. It would seem that, though the mode of conducting the campaigns varies somewhat, the usual practice is to put through the whole accumulation of tin ore by continuous working and afterwards to treat the slags as described. The cost at Tras may be estimated as follows per 24 hours:

12 picul of charcoal @ $1.50		$18.00
Labour: Head smelters,	$1.75	
6 coolies @ 50 cents,	3.00	4.75
Tools and wear of furnace, say		2.00
Total per 24 hours		$24.75

or about $11 United States currency, making the smelting cost about 73 cents (or say 3 shillings) per 100 pounds of metallic tin produced. This does not include the after-treatment of the slags. Although the air furnace is decidedly more simple in construction than the blast furnace, there are good reasons for believing that the former is a modification or development of the latter, and that it replaced

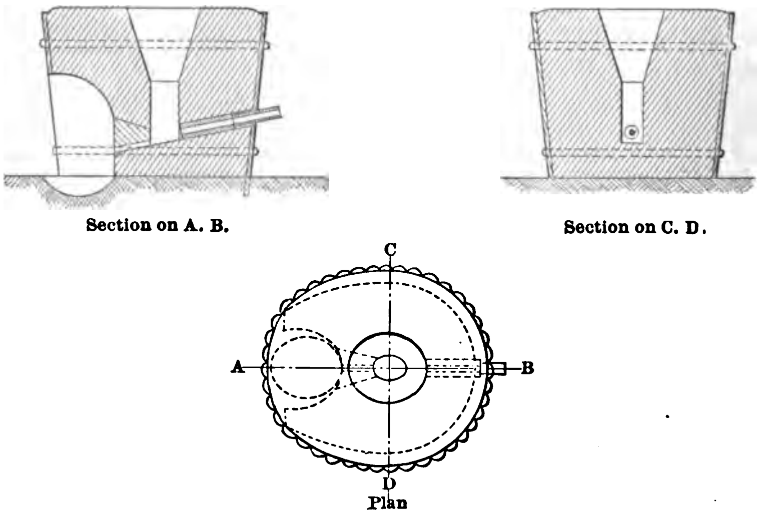


FIG. 18. — Chinese Blast Furnace at Dreda. Scale 16″ to one foot

some form of blast furnace in suitable districts. The air furnace is now, however, rapidly becoming extinct, owing to the difficulty of getting suitable charcoal, and to the fact that under British protection attempts are being made to preserve the forests, and to prevent promiscuous destruction of the best timber.

Accordingly the blast furnace is now the more frequently used in the Malay Peninsula. Although varying considerably in details the principle is always the same. The furnace here illustrated (Figs. 18 and 19) is one of a number, all practically identical, erected in a very remote district on the boundary between the Siamese-Malayan States of Reman and Jalor, the center of which is a flourishing Chinese

village known as Dreda. This spot had rarely, if ever, been visited at the date of writing (1895) by any European except the writer, hence it may be taken for granted that the furnace there used presents the purest Chinese type unaffected by European influences; it is perhaps rather lower than the average of those in general use elsewhere. It is built like

FIG. 19. — View of Chinese Furnace at Dreda

the air furnace, but is sometimes very roughly hooped, and only lasts for a short campaign. The front of the crucible forms an arch about 8 inches high, which is closed when at work by a lump of clay with a tap-hole about 1 inch in diameter through it, as shown in Fig. 18. In case of need the whole lump can be taken out without destroying the furnace. Through a circular aperture in the back of the furnace a tuyere made of clay, care-

fully dried and baked, is inserted, and may project to a greater or less distance into the furnace; it is generally about 22 inches long, 2½ inches inside and 5 inches outside diameter, and is connected by means of a short bamboo blast-pipe with the bellows. The latter appliance consists of a hollowed-out tree trunk 12½ inches in diameter and about 10 feet long; the piston is a block of wood attached to a long wooden rod that works through a wooden stuffing-box at one end; it is neatly packed with feathers or leaves. There are flap valves at either end of the casing for the intake, and similar delivery valves opening into a narrow wind-chest that runs along the front of the tree trunk, so that it forms a double-acting blowing cylinder; all leaks are stopped with clay. One man works the bellows for half an hour or so at a time, when he is relieved; sometimes two men work it for a short time, probably when the head man judges that more blast is required. The average rate of working is somewhat above 10 strokes per minute, so that it may be roughly calculated that the furnace receives about 75 cubic feet of air per minute. As a rule the blast is stopped for between one and three hours in the middle of the day. The ore in this district is of very varying quality, and the statements of the various smelters are decidedly discordant as to the working of their furnaces. The average of their statements is that a furnace smelts between 1,250 and 1,760 pounds of ore per 24 hours, with a consumption of between 600 and 750 pounds of charcoal. The daily production of tin is between 10 and 12 ingots, which here weigh 60 kati each, or say 800 to 960 pounds of metallic tin. The price of the charcoal, which is of rather inferior quality, is in this district 4 baskets of 30 catty each for $1; this would make the cost of fuel about 22 cents United States currency to each 100 pounds of metal; according to another smelter's statement the cost is about 35 to 40 cents per each 100 pounds of metal. It will be seen from the figures here given that the blast furnace has a smaller output than the air furnace — the latter having a much greater cubic capacity, but that it works

with a much smaller consumption of charcoal, beside using charcoal of inferior quality. There appear to be generally about five men on a shift working the blast furnace. The method of collecting and casting the tin, and of removing the slag, are identical with the corresponding operations in the air furnace. The system of working varies in different districts. In the Dreda district the smelting campaign seems to be carried on continuously from start to finish; in other places the work is intermittent. Only a rough estimate can be made of the cost of smelting in the Dreda district, the cost per 24 hours being probably somewhat as follows:

Charcoal, 15 baskets at 25 cents each	$ 3.75
Labor, (head smelters, $1.75, 10 coolies at 50 cents each, $5.00)	6.75
Furnace repairs and tools, say	3.00
Total	$12.50

or about $5.50 United States currency, making the cost about 60 cents or about 2*s.* 6*d.* for each 100 pounds of metallic tin produced. The fuel cost is probably too low and the total cost ought to be probably 70 to 80 cents, or about 3*s.* to 3*s.* 4*d.* per 100 pounds.

It is interesting to note that in this district, in addition to tin, a natural alloy of lead and tin is smelted.* The ore is a deposit of gravel cemented by oxide of iron that contains a mixture of tinstone and oxidized lead ore, the result of the degradation of stanniferous granite and of limestone containing pockets of galena, the cementing material being derived from the oxidation of iron and arsenical pyrites. This cemented gravel is crushed and washed, the resulting mixture of tin and lead ore being smelted just like the pure tinstone. The product is an alloy of lead and tin, having the following composition:

Lead	69.4
Tin	27.9
Iron	0.7
Sulphur, arsenic, etc.	2.0
	100.0

*On the River Telubin, by Henry Louis. *The Geographical Journal*, September, 1894.

In Perak the furnace and general mode of working closely resemble the Banka practice, which will be described in detail below. The furnace consists of a roughly cylindrical or rectangular block of clay or rough brickwork, about 6 feet square and of nearly the same height, the furnace proper being a cylindrical or slightly tapering cavity lined with clay, about 2 feet to 2 feet 6 inches in diameter and 5 feet deep. The rear wall of the furnace is built up 2 feet or so above the general level of the furnace top so as to form a kind of screen, apparently to protect the blowing cylinder from damage by pieces of burning charcoal thrown out by the blast; the tap-hole and float are similar to those of the ordinary Chinese furnace. The tuyere and blowing cylinder are identical with those previously described, except that the latter is perhaps a little larger and is generally worked by three men. Mr. Doyle * states that the furnaces work the whole year round, but only at nights; a fresh lining and tuyere are put in every day. He gives the following as the average cost of smelting at the time of his writing, the costs being reckoned on a night's work:

Charcoal, 18.58 picul †	$31.96
1 overman	1.20
2 relays of 3 coolies	5.40
Food and miscellaneous stores	2.35
Total	$40.91

Ore smelted in one night, 32 picul; metallic tin obtained, 19.52 picul. This would make the cost of smelting about 62 cents per 100 pounds of tin; it is right to observe that when Mr. Doyle wrote, the value of the dollar in the Malay Peninsula was about twice what it was at the time that the author was there. Mr. J. E. De La Croix ‡ states that although smelting used formerly to be done only at night in Perak, it is now carried on day and night at some furnaces. The rectangular brick-built

* Patrick Doyle: *Tin Mining in Larut*, 1879, p. 19.

† The Larut picul is the heavy or Malay picul, weighing nearly 150 lbs. avoirdupois.

‡ *Les Mines d'Etain de Perak*, 1882.

furnace is, according to him, 6 feet high, 7 feet 6 inches broad, and 5 feet 6 inches deep; the furnace proper is semicircular, 18 inches in diameter, and the tuyere is inclined 45°. Such a furnace, with blower complete, costs about \$100. It treats 36 picul of ore per night at a cost of \$2.85 per picul. Smaller furnaces, closely resembling those in use at Dreda, are also employed. It is stated that quite recently the Chinese have succeeded in replacing a portion or the whole of the charcoal by desiccated or torrefied wood, thus producing a marked economy, but no definite data on this subject are available.

In other cases a furnace appears to be used in Perak for ore-smelting, practically identical with that used in Selangor for slag-smelting only, to be described below. A full account of such a furnace has been published by Mr. F. Owen,* who describes a Chinese smelting house in Perak, in which there are 8 furnaces, each having a smelting capacity of nearly 12 cwt. of black tin per 24 hours, when working on ore containing about 67% of metal. The furnace is almost identical with the slag-smelting furnace shown in Fig. 20, p. 58; the bottom of the furnace consists of an iron pan, 24 inches in diameter, 12 inches deep, the thickness of the metal being ½ inch; such pans are made in China, and the Chinese article is preferred by the Chinese smelters to an English one. The body of the furnace is composed of quartzose sand, and refractory local clay; it is hooped with 4 rings of ½-inch iron and supported by 12 longitudinal bars of ¼-inch iron; the furnace body is 4 feet high and 2 feet 6 inches in diameter; the basin is 1 foot 6 inches above the ground, carried on a ring of ½-inch iron supported on 4 legs of ¾-inch round iron. The furnace inclines outward from the vertical at an angle of about 5° (compare Fig. 20); the tap hole is 3 inches in diameter, strengthened with an iron hoop, and is situated 6 inches above the bottom of the furnace. The float consists of an iron basin, 1 foot 6 inches

* *Mining in Perak*, by F. Owen, Trans. Inst. Min. and Met., Vol. VI, 1906, p. 76.

in diameter and 6 inches deep, let into the ground in front of the tap-hole; the tuyere is made of iron; it is 2 inches in diameter and is placed 6 inches above the bottom of the furnace. The blower, made of a hollowed-out tree trunk, is 9 feet long and 9 inches in diameter, with a leather valve 3 inches in diameter at each end. The cost of such a furnace is about as follows:

Iron work delivered	$25
Clay, sand, etc.	5
Blowers	10
Labor	10
Total cost	$50 = £5.10

or say about $26.50 U. S. A. currency.

The life of such a furnace is about two years.

The furnace is operated by 4 men, working in pairs, one at the blower and the other attending to the furnace, in shifts of 6 hours, so that each man works 12 hours out of the 24; each gang is paid $5 or 11*s.* per day. The charcoal costs 50 to 60 cents per picul (20 cents to 25 cents U. S. A. currency per 100 pounds); the molten tin is tapped out by opening the clayed-up tap-hole with an iron bar, when the metal flows into the float, from which it is ladled into sand moulds, producing ingots of 112 pounds each. The furnace campaign lasts 30 days, when it is stopped for repairs; the ore smelting recovers about 40% of the tin contained in the ore. The slag is re-smelted separately, exactly as in Selangor, the account given by Mr. Owen coinciding closely with the practice as observed by the author.

L. Giraud* also states that this type of furnace, which he calls the Siamese or Tongkah furnace, is used for ore-smelting in the state of Perak, and that in some cases mechanical fans are coming into use. He gives the cost per 24 hours of working such a furnace as follows:

* Mémoires et Travaux de la Société des Ingénieurs Civils de France, 1909, vol. I, p. 47.

Labor	$ 7.00
Charcoal, 14 piculs @ 88 cents	12.32
Wood and tools	0.50
Miscellaneous	0.50
Total	$20.32

The production in 24 hours is 12 ingots of 92 kati each, or about 11 piculs, making the price $1.84 per picul, or about 78 cents U. S. A. currency, or 3*s.* 3*d.* per 100 lbs. at the present rate of exchange.

The metal requires refining, but the latter operation is rarely performed by the Chinese but by the Straits Trading Co. or the Eastern Smelting Co., to whom the Chinese mostly sell their tin. When a mechanical fan is used, the cost of labor comes down to $5, so that smelting thus comes a little cheaper. The slags are re-treated in the usual way until the final loss of tin is under 1%.

Refining costs about 20 cents per picul, or 7 cents U. S. A. currency, or 3½*d.* per 100 lbs. of refined metal obtained. The crude tin leaves on refining about 15% of residue containing 25% of tin, equal to a loss of 3.38% of the metal charged.

Treatment of the Slag. — The slag collected during a campaign is first treated mechanically to separate the prills of metal that it contains. It is crushed in various ways, but mostly in small foot-mills, which are simply tilt-hammers worked by the foot. The body of the hammer is of wood and the head consists of a piece of hard stone; they are often constructed without a particle of iron. Similar foot-mills have been fully described by the writer* in a paper on gold-milling in the Malay Peninsula. The slag is pounded in these little mills and the powder is then washed in a short wooden sluice, 5 to 6 feet long and 12 to 15 inches wide, with a light stream of water, in precisely the same way that the tin ore is cleaned. The tin thus obtained is simply melted, and the slag is collected and smelted

* Henry Louis: *Trans. Am. Inst. Min. Eng.*, "A Chinese System of Gold Milling," Vol. XX, 1891, p. 324.

in the ordinary ore furnace, more tin being thus obtained. The slag produced in this second operation is treated in the same way once more, and the slag resulting from the third fusion is sold to the slag smelters. The slag furnace is shown in Fig. 20; it consists of a clay body, iron bound,

Fig. 20. — Chinese Slag Furnace

about 36 inches high and 27 to 30 inches outside diameter. The bottom consists of a cast-iron basin into which clay is rammed, and it is carried on short iron legs so as to be 12 to 18 inches above the ground. There is a small tap-hole in front and one clay tuyere about $1\frac{3}{4}$ inches in inside diameter and $10\frac{1}{2}$ inches long; the blowing cylinder is of wood quite similar to that used for the large furnace,

but much smaller, being about 5 to 6 feet long and 9 inches in diameter. The slag, after being pounded and washed, is smelted in this slag furnace; good slag is said to yield 100 pounds of metal from 700 pounds of slag, and with good charcoal it is possible to get 6 to 8 slabs of tin weighing 50 kati each, say about 470 pounds altogether, with a consumption of 15 picul (say 2,000 pounds) of charcoal. From these figures it would seem that slag requires 30% of its weight of charcoal to smelt it. The slag furnace here described is situated at Sungei Besi in Selangor; in this locality charcoal of a quality sufficiently good for the slag furnace is not dear, costing only 60 to 80 cents per picul, say 20 cents to 26 cents U. S. A. currency (10*d.* to 13*d.*) per 100 pounds. Two men appear to be enough to work one of these furnaces. Another slag smelter near Kuala Lumpor stated that he was smelting about 2,000 pounds of slag in 24 hours and was getting a little over 100 pounds of tin from it; he was evidently working a much poorer slag. The molten tin drops into a float, which is again merely a hole in the ground lined with clay, the treatment being identical with that in the ore furnace. The resulting slag is again pounded, washed, and re-smelted in the same way. The slag resulting from this operation is pounded and washed, and if the smelter judges it to be worth while, he will smelt it once more, though this is not often done. Pounding and washing is always the last stage of the process. Concentrates thus obtained are sometimes treated by heating to redness in an iron pot, when the tin liquates out, leaving a slaggy mass that can be treated further if required.

The average yield of metal from ore throughout the Malay Peninsula is evidently higher than might have been expected, being probably about 65%, including the metal recovered from the slags. The average amount of tin contained in the ore is probably a little under 69%, so that the loss would amount to about 6% of the tin in the ore. A good deal of this is probably left in the slags, so that the loss due

to volatilization and to ore carried off mechanically must be comparatively small. The Chinese smelters keep their furnace tops cool by throwing water on them from time to time and by regulating the blast, the pressure of which is of course very light. Most of the volatilization that takes place seems to be at the tap-hole; incrustations, consisting largely of oxide of tin, can generally be scraped from the arch of the furnace above the tap-hole, but no attempt seems to be made to collect this material.

Practically the whole of the tin produced in the Malay Peninsula is forwarded to Singapore or to Penang, whence it is re-shipped to the various markets. Malacca was at one time one of the chief ports, whence the name of Malacca tin is derived, but now there is absolutely no tin whatever shipped from there.

Refining the Smelted Tin. The metal produced in ore-smelting is soft and apparently fairly pure,* but needs refining before it is fit for the European market. Slag-metal is generally very impure, and is for the most part simply re-melted and re-cast, and shipped to China, where there is a market for hard tin. The refining is all done by large Chinese or European firms in Singapore and Penang; the tin is melted in open, almost hemispherical cast-iron pans, 4 to 5 feet in diameter and 1 foot 9 inches to 2 feet deep, set over a wood fire. The ingots as received are melted down in these pans, the liquid metal is skimmed, some grease is thrown on the surface, and after being allowed to stand for some hours it is ladled into iron moulds. The dross skimmed from the surface, and that deposited on the bottom of the pan, is consolidated into cakes by beating while hot, and is exported to Amoy, where it appears to be utilized in some way; it contains 40 to 50% of tin, partly as metal and partly as oxide. The loss in refining is between 0.4 and 0.8%; the cost including loss is between 20 and 30 cents per picul, or about 7.5 to 11 cents U. S. A. currency (say 4*d.* to 5½*d.*) per 100 pounds.

*According to notes kindly supplied by Mr. John McKillop, late of Pulo Brani, Singapore.

Mr. J. E. De La Croix * describes the refining process at Penang in very similar terms. According to him the pot is of wrought iron, 5 feet in diameter and 25½ inches deep, weighs 1,300 to 1,700 pounds, and can contain 40 picul (say 5,500 pounds) of tin; it is heated by a reverberatory wood-fire. The cost of the entire refining furnace is about $235, of which the pan costs $70 to $90. Two hours after the fire has been lighted, the tin is charged, and is all melted in two hours; after stirring and skimming, etc., in about half an hour more, 15 picul of tin are ladled out and cast into moulds; 15 picul of unrefined tin are then charged into the pot, and so the process continues. There are thus 205 picul treated in 24 hours, the yield of refined tin being 196 picul, equal to a loss of about 4%. The fuel used is cord-wood, of which 200 pieces are burned in the 24 hours; there are six men to a furnace, who are paid altogether 4½ cents per picul of refined tin produced. The total cost of refining is given as 52 cents per picul. It must be remembered that when Mr. De La Croix wrote, the Straits dollar was worth about 80 to 90 cents United States currency.

The following is an analysis of Chinese refined tin of average quality from the Malay Peninsula:

Sn	99.87%
Sb	0.03%
As	faint trace
Pb	0.01%
Fe	0.09%
Cu	none
Total	100

The Chinese Process at Banka. — As previously mentioned, this process was introduced into Banka about the middle of the eighteenth century and continued in universal use until about 1870, when certain improvements, to be referred to below, were introduced by the Dutch government engineers. The original Chinese furnace† was oblong or rect-

*Op. cit. p. 59.

†*Jaarboek van het Mijnwezen in Nederlandsch Ooost-Indie*, 1872, I, p. 127; P. H. Van Diest: "Het Tin Smelten op Bangka."

angular in plan, about 13 feet long by 5 feet wide, and 4 feet 3 inches high. It was made of sandy clay well rammed, and the furnace proper and the arch above the float were cut out in it, so that the shape of the interior is very similar to that of the Larut furnace already described, which latter was indeed originally introduced by the Chinese from the Archipelago. The forehearth or float and the horizontal blowing cylinder are also practically identical. The fire is started in the usual manner, and tin ore and charcoal are thrown in as required; the smelter keeps the tap-hole open by constant poking with a thin sapling, and in doing so pulls out a certain quantity of charcoal, unreduced ore, and thick, sticky slag, all of which are at once returned to the furnace. As soon as enough tin has accumulated in the float to make 18 or 20 ingots, it is ladled out and poured into moulds; these were originally of sand rammed around a wooden pattern, but were subsequently of cast-iron; when the tin in the mould is on the point of setting, an iron stamp bearing the word "Banka" is pressed into the upper surface.

Smelting is carried on only at night, the usual hour for commencing being from 8 to 10 P.M., and continuing until 6 to 7 A.M. There is only one smelting campaign every year, commencing about November, or October at the earliest, and always concluding by the end of December; the time of beginning the campaign is varied in accordance with the quantity of ore on hand, and its average duration is from 20 to 30 nights. At the beginning of the campaign each furnace will yield about 60 ingots of tin per night, but towards the end only about 50, the ingot weighing 65 to 70 pounds. After every four nights' smelting, the furnace is laid off for a night and allowed to cool down for any needful repairs. The charcoal used is of good quality and is prepared by the gang of charcoal burners employed by each mine or smelting establishment; it is burnt in piles about 35 feet long, 12 feet wide, 6 feet high at the front and 9 feet at the back, composed of stout logs laid parallel to the shorter side of the pile, which is then covered with a layer

of earth in which holes are left at various heights. The process of burning takes about a fortnight, and when complete the charcoal burner brings the coal into the smelting house. A charcoal burner can supply in one year enough charcoal to keep a furnace going for five or six nights, *i.e.*, enough to smelt about 150 picul (about 20,000 pounds) of tin. Fully 7 parts by weight of charcoal are required for the reduction of 10 parts of well-washed ore.

The slag produced contains prills of tin and unreduced oxide of tin. In five to six nights' ore-smelting there is enough slag produced for a night's slag-smelting, yielding some 30 to 40 ingots. The slags produced in this operation are re-smelted, and then sold to the slag smelters, who dress and re-smelt them several times. Their last slag still contains several per cent of tin. The mines smelt out on the average about 69% of metal from the ore, and the slag smelters about 1%, so that the total yield is about 70% of the weight of the ore, which actually contains about 75%.

In the year 1854 * a commission to hold an inquiry into the amount of tin lost by this method of smelting was appointed by order of the Dutch government, owing to the fact that slags had been found to contain as much as 19% of tin, out of which from 1 to 6% was in the form of prills. It was estimated at that date that Banka was producing annually 80,000 picul of tin and 8,822 picul of slag, supposed to contain on the average 15.7% of tin, equal to an annual loss of 1,386 picul. This commission carefully watched a short smelting campaign conducted by the Chinese in one of the best smelting works on the island, and reported the results fully. The smelting works contained two furnaces; smelting commenced on the night of November 1st, 1854, and was continued nightly, there being no smelting on the

**Jaarboek van het Mijnwezen in Nederlandsch Oost-Indie*, 1878, II, p. 29; C. De Groot: "Rapport over de tin slakken, welke op Bangka onbenuttigd worden weggeworpen."

nights of the 4th, 8th, and 12th, so as to enable the furnace to be repaired. Ore was smelted on eight nights, and then the slag-smelting commenced, the slags produced during the slag-smelting being re-smelted three times, or until the Chinese headmen declared they could no longer treat them at a profit. The slags were then sold to slag smelters, who crushed, washed, and smelted them, and finally threw them aside as no longer payable. The results of the ore-smelting are shown in the subjoined table, all the weights being in Amsterdam pounds (about 1.07 pounds avoirdupois):

Number of Night	Furnace Number	Weight of Dry Ore Smelted	Weight of Tin Produced	Weight of Charcoal Consumed	Number Hours in Shift
First	1	8,148.0	4,127.2	3,877.7	15¾
First	2	7,878.4	4,421.0	3,842.1	16
Second	1	6,050.4	3,641.1	3,104.6	14
Second	2	5,986.1	3,679.9	3,104.6	14¼
Third	1	5,982.9	3,456.0	3,569.0	14
Third	2	5,851.5	3,789.7	3,569.0	14½
Fourth	1	6,019.8	3,591.1	3,132.0	12¼
Fourth	2	6,018.0	3,741.0	3,132.0	12¼
Fifth	1	6,462.9	3,796.0	3,936.0	13½
Fifth	2	6,404.2	3,877.6	3,660.5	13½
Sixth	1	6,361.1	3,624.0	3,186.0	13
Sixth	2	6,224.9	3,739.3	3,283.5	13
Seventh	1	5,768.7	3,637.0	3,276.4	12¾
Seventh	2	5,800.6	3,561.3	3,346.1	12½
Eighth	1	6,076.3	2,682.6	3,032.2	12¾
Eighth	2	6,115.7	3,788.1	3,103.8	12¾
Totals	—	101,149.5	60,162.9	54,155.5	216¾

The account of the slag-smelting is rather more involved because it occasionally happened that two different slags were being treated simultaneously, and because various furnace residues were smelted with the slags. The following table shows the chief results obtained, the weights used being Amsterdam pounds:

Slags Treated	Weight of Slags	Weight of Tin Extracted	Percentage of Metal Extracted
I. Slag produced in ore-smelting......	19,093.5	5,938.8	31.1
II. Slag from first slag-smelting........	9,733.7	2,517.9	25.7
III. Slag from second slag-smelting	7,237.3	1,047.1	14.4
IV. Slag from third slag-smelting	3,141.9	325.7	10.3
V. Slag from fourth slag-smelting	2,916.5	643.1	22.0
Totals	42,122.9	10,472.6	24.9

Of these, the first four slags were treated by the mine-owners, the weight of charcoal consumed being 17,375 pounds, and the time employed 73¾ hours. The slag was then sold to the slag smelters, who used in smelting it 977 pounds of charcoal and took 13¼ hours in the smelting, using a smaller furnace than was used for ore-smelting. The slag was thrown away in three parcels as follows:

1,663.1 lbs. of slag assaying 20.5% of tin, equal to....	340.9 lbs. of tin.
3,049.1 lbs. of slag assaying 20.33% of tin, equal to....	620.0 lbs. of tin.
2,988.4 lbs. of slag assaying 20.33% of tin, equal to....	249.0 lbs. of tin.
7,700.6 lbs. of slag, equal to the total of.............	1,209.9 lbs. of tin.

The above results include the tin recovered by the mechanical treatment of the slags. According to G. P. A. Renaud,* slags in Banka are crushed by means of a kind of iron flail, to pass through a sieve made of bamboo with a $\frac{13}{16}$-inch mesh, and are then washed in a sluice-box 18 feet long and 18 inches wide. The washed material is broken down to pass a sieve of $\frac{5}{16}$-inch mesh, and again washed repeatedly; the grains of tin are then separated out, and the residual slag may be smelted.

An analysis of the results above tabulated shows that the average length of the night's shift of these smelting furnaces was 13½ hours, and that they treated per night and per furnace an average of 6,743 pounds avoirdupois of dry ore, with a consumption of 4,011 pounds of charcoal and the production of 3,610 pounds of metallic tin. In the slag-

**Jaarboek van het Mijnwezen in Nederlandsch Ooost-Indie*, 1886, II, p. 68, "Behandeling van de tin slakken op het eiland Bangka."

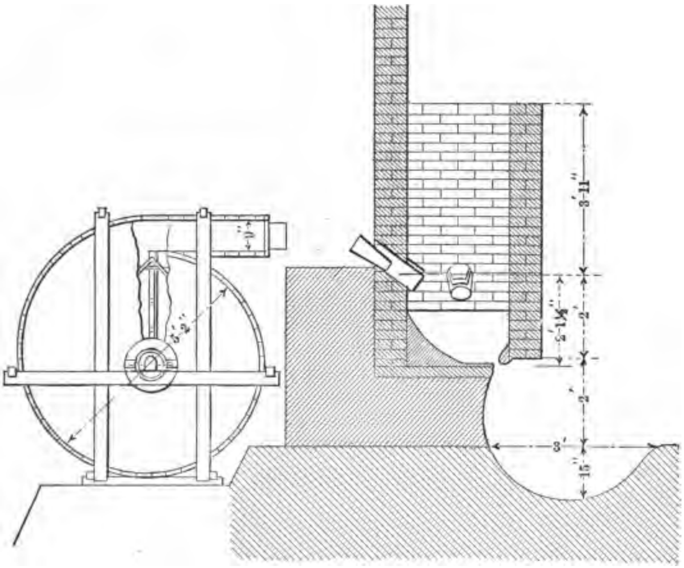
smelting seven nights' work was done, the average length of the shift being 12½ hours; each night's work cannot be quite fairly averaged, yet by working out the above figures for the first four slags only, it would seem that one of the large furnaces could smelt on an average 6,970 pounds avoirdupois of slag with a consumption of 3,089 pounds of charcoal. The ore yielded in the ore-process 59.480% of metal, and in the slag-smelting 10.353%, giving a total yield of 69.833%. There were thrown away in the refuse slags 1.196% of tin, making the gross amount of metal present 71.029%, not allowing for losses by volatilization, etc. The consumption of charcoal was 102.6% of the weight of the metallic tin produced; upon the weight of the ore smelted it was 53.5% in ore-smelting and 18.1% in slag-smelting, making a total of 71.6%.

These figures illustrate very thoroughly the technical and economic results obtainable in the Chinese furnace, and a few others obtained by a government commission fourteen years later will be given presently. From these the cost of smelting under any given set of conditions can be approximately calculated; the following are actual figures obtained from smelting on a rather small scale in the island of Singkep, the furnaces used being similar to those in Banka, but much smaller, and being rented to the owners of the ore, so that the first item represents a small profit besides wear and tear and interest on capital outlay. Cost of smelting per night:

Furnace hire	4.06 fl. *
Wages (smelter, 2.80 fl.; helper, 1.68 fl.; 6 coolies, 6 fl.)	10.48 fl.
Charcoal (1,323 pounds avoirdupois)	27.72 fl.
Total	42.26 fl.
Equal to	$16.90 U. S. A. currency
Ore smelted per night	2,640 pounds
Metallic tin obtained, about	1,750 pounds
Cost of smelting per 100 pounds metallic tin	$ 0.96 U. S. A. currency (Say 4*s*.)

* Exchange calculated at 1 florin equal to 40 cents United States currency.

As previously stated, attempts were made in various way to improve this original Chinese method, but none of these obtained anything like general acceptance with the exception of the modifications introduced in 1868 by Dr. C. L. Vlaanderen; his furnace, known as the rectangular or Vlaanderen furnace, was experimented upon, and was found to extract about 3% more metal than the old form, with a smaller consumption of charcoal, with less labor, and in



Sectional Elevation on line A. B.

1 0 1 2 3 4 5 6 7 8 9

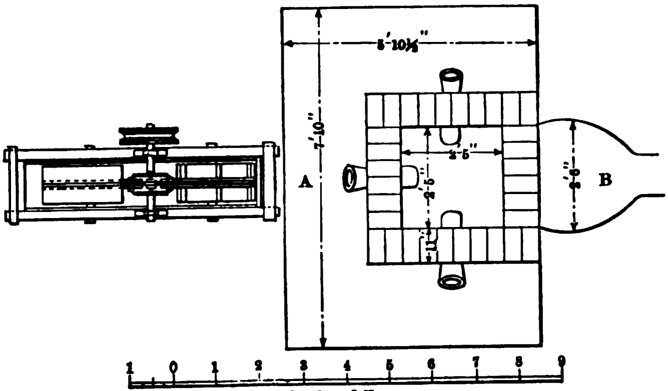
Scale of Feet

FIG. 21. — Vlaanderen Furnace

less time. In 1875 there were ninety of these furnaces at work in Banka, and now they are almost exclusively used both in Banka and in Billiton. The main* improvement is the production of the blast by means of a centrifugal fan, thus saving about 0.40 fl. per picul of tin. The furnace is shown in vertical section plan and in Figs. 21

* *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indie*, 1872, I.

and 22. The inventor's own description of his furnace is as follows: A foundation is excavated to a depth of some 7 feet; the pit is paved with stones, and clay, such as is used by the Chinese in furnace building, is rammed in. On this foundation the furnace is erected by ramming the same kind of clay into a wooden frame 5 feet 6 inches wide and 8 feet long to a height of 4 feet 9 inches. When the clay is dry the frame is removed, and the furnace proper and the fore-arch are cut out in the block, the arch being similar to that of the old furnace, and the furnace cavity being 3 feet 9 inches square and 28 inches deep; this cavity is floored with a layer of bricks. In the middle brick of the



Scale of Feet

Plan

FIG. 22. — Vlaanderen Furnace

second row an inclined hole must be cut to form the tap-hole. Upon this floor the furnace is built up of ordinary good bricks to the dimensions shown in Figs. 21 and 22, taken from the above-quoted work, which show both the furnace and the blowing fan. There are three tuyeres, holes for which must be left. The inside of the furnace must be lined 3 inches thick with the same clay as is used by the Chinese for daubing their furnaces, consisting of fire-clay mixed with a little salt. Clay tuyere-pipes, preferably thickened on the top side, are used; they are much stouter than those used in the old furnace, and therefore

only need renewal every two or three nights. The tuyeres are connected to the fan by means of a horseshoe-shaped blast-pipe, which may be of wood, and made air-tight with clay. The blower has the shape of an ordinary centrifugal fan very simply constructed, with four sheet-iron blades; it is driven by means of a very crude rope gearing, passing over grooved wooden sheaves, from a small overshot water-wheel of the usual Chinese type.

When the furnace has been built and well dried by a small fire, it is ready for use; after a run it must be well cleaned of all adhering pieces of slag, etc., the clay lining repaired, and the tuyeres renewed in case of need. The furnace is then filled with ignited charcoal and the fan started at about 300 revolutions per minute. As soon as the top layer of charcoal is red-hot, the first tin ore is charged, and then ore and coal are fed in alternate layers in the proportion of 35 kgms. (77 pounds) of the former to 30 to 32 kgms. (66 to 71 pounds) of the latter. The whole of the night's charge of 3,000 kgms. of ore (6,614 pounds) is charged in 8 or 9 hours. After seven or eight nights of ore-smelting, a night's slag-smelting is done, the slag being broken into pieces about the size of a hen's egg and mixed with 20% of its weight of coral limestone, broken to the same size. This is charged in layers of 50 to 54 kgms. (110 to 120 pounds) of the mixture and 30 to 32 kgms. (66 to 71 pounds) of charcoal.

A Government Commission was appointed in 1868 to examine and report on this furnace. The following comparative test is described in much detail by the commission. Two of the old Chinese furnaces and one Vlaanderen furnace were employed to smelt a parcel of ore which assayed 76.39% of tin. The two Chinese furnaces worked 8 shifts, or altogether 134 hours 22 minutes of the time of one furnace. The quantity smelted was 51,233 pounds of wet ore, equal to 50,678 pounds of dry ore, or 6,335 pounds per furnace in a shift of 16¾ hours. The slag, amounting to 5,201 pounds, was re-smelted twice and then sold to the slag smelters. The charcoal used was: In ore-smelting, 33,215 pounds; in

the first slag-smelting, 2,544 pounds; in the second slag-smelting, 1,909 pounds—total, 37,668 pounds. The quantity of metallic tin obtained was as follows: From the ore-smelting 33,146 pounds; from the first slag-smelting, 1,288 pounds; from the second slag-smelting, 338 pounds; by the slag smelters, 132 pounds—total tin obtained, 34,904 pounds. Percentage of metal obtained from the dry ore, 68.87. The slag rejected by the slag smelters still retained 9% of tin.

The Vlaanderen furnace worked for 3 shifts of 48 hours and smelted 21,078 pounds of wet ore, equal to 20,873 pounds of dry ore. The amount of slag produced was 2,132 pounds, and this was smelted once in admixture with 425 pounds of broken coral limestone. The quantity of charcoal used was: In ore-smelting, 13,417 pounds; in slag-smelting, 2,055 pounds—total, 15,472 pounds. The amount of metallic tin produced was: From the ore, 14,287 pounds; from the slag, 762 pounds—total, 15,049 pounds. Percentage of total metal from dry ore, 72.13. The residual slag contained only 2% of tin, and neither it nor that obtained in the Chinese furnaces paid to re-smelt.

It will be seen that the Vlaanderen furnace produced a saving of time amounting to about 18%, a saving of coal to the extent of about 5%, and extracted over 3% more metal from the ore, these results accounting sufficiently for its very general adoption by the Chinese in the Malay Archipelago. The costs of smelting in this furnace have been calculated by G. P. A. Renaud * in more recent times; in his opinion the centrifugal fan is the only improvement that the Chinese smelters owe to European science. He calculates the cost of a small smelting house with one furnace, fan, etc., complete, as follows, the house being, as usual, a substantial high-roofed shed, thatched with leaves and open at all four sides:

* *Jaarboek van het Mijnwezen in Nederlandsch Ooost-Indie,* 1884, I, p. 5: "Over de Chineesche ontginningswijze van Tinerts op het Eiland Bangka."

Shed	500 fl.
Furnace	150 fl.
Fan and blast-pipes	200 fl.
Water-wheel and driving-pulley	150 fl.
Ditches for the water supply	150 fl.
One set of furnace tools	90 fl.
Total	1,240 fl.
Equal to	$496 U. S. A. currency

On this basis he considers that 215 fl. should be written off annually for repairs and depreciation; taking the furnace to smelt 35 picul per night, this amounts to 0.60 fl. per picul if the furnace works for 10 nights in the year, and to 0.30 fl. if it works for 20, the usual smelting campaign lying mostly between those limits. Charcoal is delivered to the furnaces in quantities sufficient for a night's work, say about 53½ picul, at prices that range from 45 to 60 fl. in different districts, so that the price of the picul of charcoal may be averaged at about 1 fl. In round numbers 100 picul of ore require for their smelting 100 picul of charcoal, and produce 68 to 70 picul of tin, together with slags that yield some 3 picul more.

The daily cost of smelting with a production of 35 picul, say 4,670 pounds of tin, may be set down as follows:

Tuyere-pipes	1.50 fl.
Rope for driving gear	1.00 fl.
Furnace tools	18.00 fl.*
Saplings for picking out tap-hole	0.50 fl.
Wages (smelter, 7 fl; 2 helpers, 3.60 fl.; 3 coolies, 1.50 fl.; rations for 6 men, 6 fl.)	18.10 fl.
Charcoal	53.00 fl.
Rations for charcoal-burner	1.00 fl.
Total daily cost	93.10 fl.

equal to $37.24,or 2.66 fl. per picul, which, with depreciation, etc., as above, makes the total cost of tin-smelting from 3 to 3.25 fl. per picul (90 to 97 cents U. S. A. currency (or say 3*s.* 9*d.* to 4*s.* 1*d.*) per 100 pounds) of metal.

This appears still to be the method of smelting in use to-day; it is significant that the mine reports of the Neth-

* This is as given by the Chinese, but would seem to be too high.

erlands East Indies contain no accounts of tin-smelting subsequent to those above mentioned.

The tin produced in the old type of Chinese furnaces in the Malay Archipelago was of exceptional purity, and as such always commanded a high price in the European markets. Its composition is shown by the following analyses:

	Tin from Siak*	Tin from Banka†
	%	%
Tin	99.966	99.90
Iron	0.034	0.20
Sulphur	Trace	Trace
Totals	100.000	100.10

The following are the minimum, maximum, and average amounts of the impurities present in six different samples of Banka tin:

	%	%	%
Fe	0.006	0.0196	0.0108
Pb	None	Trace	—
S	0.0027	0.0099	0.0052
C	Trace	Trace	Trace

It was accordingly never found necessary to refine this tin, an occasional re-melting being all that was ever required.

Here, however, as in most other cases, improvement in the metallurgical process has been attended with deterioration in the product. The case has been well put by Prof. A. C. Oudemans,‡ who says: "It is well known that Banka tin always had a high reputation for its great purity, and used in former times to fetch a considerably higher price

* P. Doyle, *op. cit.*, p. 23.

† *Berg-und Hüttenmännisches Jahrbuch*, 1864, *loc. cit.*

‡ *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indie*, 1890, I, p. 24: "Over Verontreiniging van Banka Tin."

than other grades. As long as the primitive Chinese method of smelting was followed there were never any complaints respecting the quality of the metal, but during the past thirty years or thereabouts — and only since the introduction of the fan blast into Banka — complaints have arisen from time to time concerning the impurity of the metal. Sometimes hard needles or grains occur in the soft mass of the tin, which have been determined to be an alloy of tin and iron." This is corroborated by P. Van Dijk,* who says that the main impurity in Banka tin is the tin-iron alloy, of approximately the formula $FeSn_2$, which is formed, not by contact of the molten tin with iron tools, but by the presence of iron compounds in the tin ore, and especially, according to J. P. J. Van der Does de Bije, by iron pyrites. The formation of this alloy is caused by excessive furnace heat, due to the fan running too fast, the temperature being high enough not only to reduce iron ores to the metallic state, but also to form and to fuse the very refractory tin-iron alloy.

Several parcels of Banka tin were rejected, owing to their impurity, about 1890, and were refined by Van Dijk, who reports his experiments fully. He has in consequence thereof proposed to introduce into Banka liquating furnaces similar to those that have been in use for some time in Billiton, and on the same principle as the Saxon liquating hearth. The furnace used by Van Dijk at Amsterdam is shown in section in Fig. 23, and is practically identical with the Billiton furnace, except that in the former the liquation plate is made of wrought iron and is heated from below, the ingots of tin being placed on this plate on a bed of charcoal; as they are gradually heated the pure tin liquates out, leaving a residue that has to be liquated at a higher temperature; the tin from the first and the second liquations was practically pure, containing respectively 99.84 and 99.79% of pure tin, the remainder being practically all iron. The residue was a heterogeneous mass consisting of metal-

Jaarboek van het Mijnwezen in Nederlandsch Oost-Indie, 1890, I, p. 5.

lic tin and a dark crystalline alloy, containing 19.2% Fe and 80.8% Sn, corresponding closely to the formula $FeSn_2$. The result of the liquating operation was to show that the original impure tin had contained about 1% of impurity, almost wholly iron, while the loss in liquating was 0.33%, due to water collected in shrinkage cavities in the ingots,

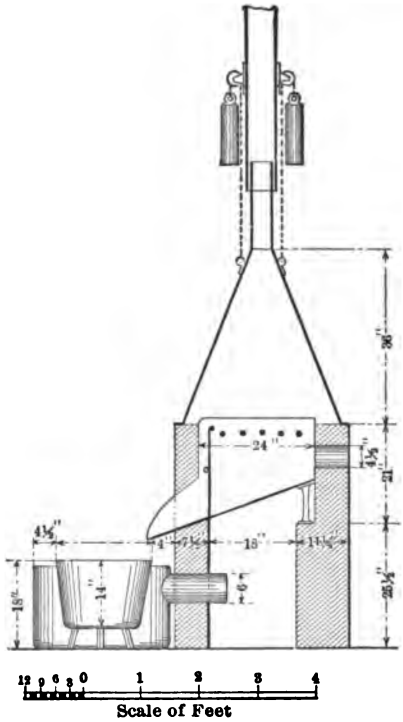


FIG. 23 — Sectional Elevation. Dutch Refining Furnace

sulphur present in small quantities, surface impurities, oxygen in the skin of the ingots, and actual loss in the furnace. Two smaller parcels were liquated in an iron muffle with a V-shaped, sharply inclined bottom, fitted with a perforated iron shelf upon which the ingots were placed; the results were similar, but the total amount of impurity was only about half as great as in the first parcel. In the latter, tungsten was detected in the shape

of a couple of small, hard, infusible lumps that formed at the bottom of the float, which consisted in the main of ferriferous tungsten. Tungsten may thus be utterly disregarded as an impurity in Banka tin. The cost of refining the large parcel of about 1,359,850 pounds was:

Fuel	976.32 fl.
Labor	3,449.12 fl.
Total	4,425.44 fl.
Equal to	$1,770.00 U. S. A. currency

The cost of refining per 100 pounds of metal at Amsterdam was therefore just about 13 cents U. S. A. currency, and would no doubt be still less at Banka.

The refining process, as now practised at Banka, has been fully described by Mr. O. H. Van der Wyck;* according to him not all the tin produced is refined, but only the last four or five blocks produced in each night's smelting, together with any that do not pass the usual physical tests, and all the slag tin. The refining furnace seems to be somewhat similar to that used in Singapore and Penang; it consists of a shallow oval iron melting basin, having a capacity of about 200 blocks of tin, say 15,000 to 16,000 pounds, over which passes a sheet of flame maintained by a hand blower, the fuel used being wood. The tin is piled up in this basin, and as it melts it flows from it into a receiver of the same size as the pan, and thence into the "controlling pan," a small pan with a capacity of about 1,100 pounds of tin. The metal that passes into this latter pan is quite pure; the tin-iron alloy accumulates in the receiver, whence it is removed by means of perforated ladles that allow the pure tin to drain away from the alloy. From the controlling pan the pure tin is decanted into a large pan, out of which it is ladled into moulds. The pans are set in sand, which stops any tin that might leak out from cracks in them; it has been found that, in the absence of sand, tin will make its way into the warm ground to a depth of as much as 13 feet.

* *Seventeenth Annual Report of the United States Geological Survey*, 1895–96, Part III, p. 239.

The tin-iron alloy is melted in small clay furnaces like the ordinary Chinese furnace, and cast into blocks; these are then subjected to liquation on a series of iron plates, down which the tin flows into a pan placed at their foot, while the separated tin-iron alloy is ultimately left as a sandy mass on the top plate; it is at present looked upon as worthless.

The loss of metal in this refining process is about 2%, but as little more than 10% of the entire tin output is refined, the loss upon the total production amounts to only 0.2 to 0.25%. Refining increases the cost of production of the metal by about 0.11 florins per picul, equal to 33 cents United States currency per 100 pounds.

The liquating hearth used at Billiton consists of three brick walls in which is set an inclined cast-iron plate, terminating in front in a pair of iron steps, below which is set a refining kettle or float at the open side of the furnace. A charcoal fire is built on the plate and is maintained by means of an air-blast through a tuyere in the rear wall. The blocks of tin to be liquated are laid on iron cross-bars a little above the fire, or laid direct on the latter. The molten tin dropping down trickles through the charcoal and runs down the sloping liquation-plate into the refining kettle, whence it is ladled into moulds.

It may be thought that too much space has been devoted to these primitive Oriental processes, but it must not be forgotten that their importance is in reality very great. As far as the writer knows they have never been adequately described, and some indeed not at all, in the English language. Moreover, we have here an almost unique opportunity of tracing the development of a metallurgical process from its crudest beginnings, such as is not easily obtainable in any other branch of the subject, and this series of processes has therefore a high historical value, more especially when it is remembered that the various stages probably present the closest analogy to the mode of evolution of the process of tin-smelting in Great Britain. Finally, far more tin is

produced by what has here been called the Chinese process than by any other. In the first place, about three-fourths of the tin production of the Malay Peninsula, or all of it that is not smelted by the Straits Trading Company, Limited, is thus produced, say about 40,000 tons of tin per annum. The whole of the tin produced in the Malay Archipelago, or about 16,000 tons, the whole of that produced in China proper, Western Siam, Burma, and the Siamese Malayan States, supposed to be about 5,000 tons, and the whole of that produced in the eastern parts of Siam and Southern China, an amount known to be large but that can only be roughly guessed as somewhere between 5,000 and 10,000 tons, is all smelted by one or other of the above variations of the Chinese process. It is also used in the north of Tonkin* near the Chinese frontier, where a little tin is produced. The same may be said of the small amount, some 40 tons, produced by Japan, together with that smelted by other minor producers in the far East. Thus it may be fairly said that this process is responsible for 60,000 to 70,000 tons of tin annually, or over one-half of the world's total production.

In addition to the above, it may be mentioned that tin-smelting has also been attempted by the Chinese in water-jacket furnaces of the American type, the blast being supplied by Root blowers. We have no data as to the result of this experiment, but unless conducted with considerable metallurgical skill, difficulties would no doubt be met with, owing to the strong blast thus obtained, which will probably cause loss of tin, both mechanically and by volatilization, and will also, on account of the higher heat produced, yield a more impure metal, which will need a more thorough refining process than the Chinese have ever yet been in the habit of employing.

* "Industrie Minérale au Tonkin," by H. Charpentier, *Bull. Soc. Ind. Min.*, 1905, p. 656.

TIN-SMELTING IN THE IBERIAN PENINSULA

The tin belt that traverses the Spanish district of Galicia and the adjacent Portuguese province of Tras-os-Montes has long yielded a certain amount of tin, and is still being explored, although the modern results so far have not been satisfactory; it would seem as though some of the mines on the Portuguese side are now considered the more promising. The antiquity of tin-smelting here may be judged from the frontispiece, which is reproduced from a plate in Agricola's well-known work, being probably the oldest known representation of a tin-smelting furnace. There is

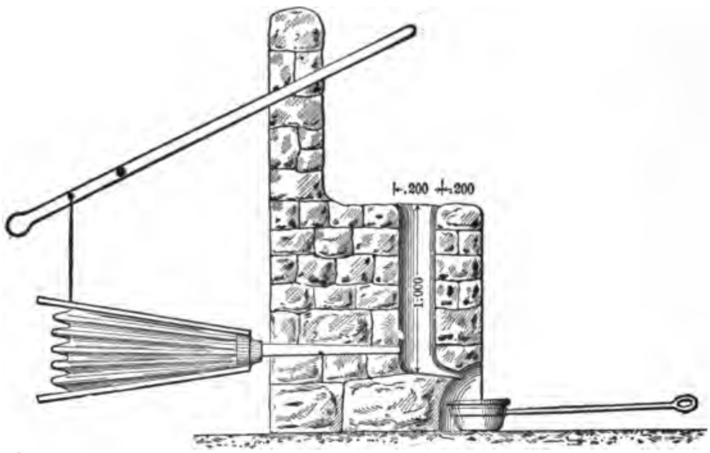


Fig. 24.—Iberian Tin-smelting Furnace

no smelting carried on now in this region, although the ore used until recently to be treated locally in small furnaces, a section of one of which, kindly supplied by Mr. A. H. Bromly, is here shown (Fig. 24). These furnaces were circular in plan, from 3 to 5 ft. high and 8 to 10 in. inside diameter. They were worked by small hand-bellows, often circular, and about 2 ft. in diameter, the blowing being done by one man. These furnaces were capable of producing about 336 lbs. of tin per day, or about 2,240 lbs. per week, consuming during the latter period about 20 large sacks of charcoal made from brushwood and roots—trees being very

scarce thoughout the district. The slag was always foul, carrying up to 33 per cent. of tin, and had to be crushed and re-smelted, and the smelting operation was always somewhat troublesome, due perhaps to the poor quality of charcoal available; unless the tuyere was kept very low down in the furnace the tap-hole was apt to "freeze up." This method of smelting seems to have practically fallen into disuse about thirty years ago, and is hardly ever seen now, but the production of tinstone is now very small. The owners of smelting furnaces usually paid the miners (tributors) a fixed price for the clean black tin produced, this price ranging from 10 cents to 15 cents per kg. ($5 to $7.50 per cwt.). The black tin was obtained by carefully breaking and hand-picking the richer portions of the vein-stuff, while the other parts were crushed small by hand with hammers and washed in small wooden tyes. The process was obviously primitive in the extreme, and the scale of operations seems always to have been very small.

TIN-SMELTING IN MEXICO

Tin ore occurs in several districts in Mexico, but always apparently in small quantity; it is smelted by the native Mexicans in small crude blast furnaces, which appear to vary but little in construction. The following description of a Mexican furnace, working in the state of Guanajuato, has been given by Mr. A. H. Bromly:*

A sectional elevation of this furnace is shown in Fig. 25, and a view of it while in operation in Fig. 26. The main portion of the furnace is built of adobe, but the shaft is of stone with a refractory lining. A double bellows, worked by two men, provides the blast, one side being pushed in while the other is pulled out. Each bellows has a separate tuyere-pipe; the hole at the back of the furnace receiving them is oval and sufficiently wide to permit the occasional

* Tin mining and smelting at Santa Barbara, Guanajuato, Mexico, by A. H. Bromly. *Trans. Amer. Inst. Min. Eng.*, Vol. XXXVI (1906), p. 227.

insertion of a cleaning bar. Since the tuyeres point directly to the tap-hole, which is always open, the blast escapes by the latter, instead of by the shaft, and there is much sublimation and loss. The tap-hole runs the full width of the bottom of the furnace, *i.e.*, 9 in., and the furnace-man keeps it clear with an iron-shod tapping-iron. With the same tool the cakes of slag accumulating from the tap are broken up and removed. A heap of charcoal is kept burning in front of the tap-hole, and the tin trickling down into the shallow float is occasionally lifted back with the tapping-iron onto

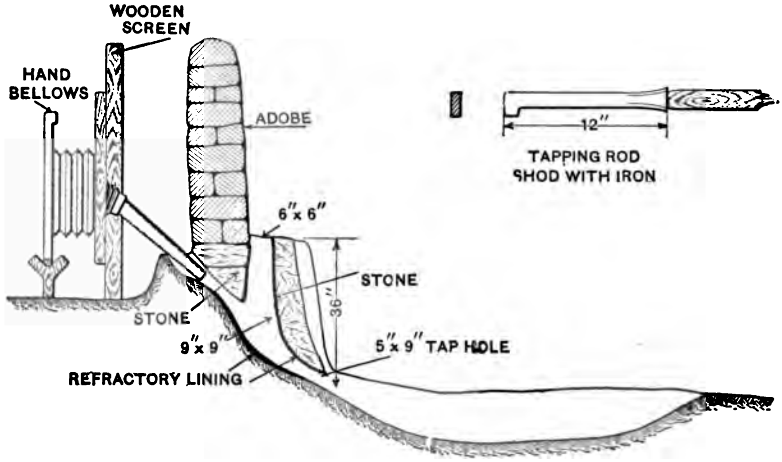


FIG. 25. — Mexican Tin-smelting Furnace. Vertical Section

the charcoal pile, and, re-melting, runs down again, each time a little purer.

The work is done by contract and the average time for twice smelting 150 kg. of ore is 16 hours. Two men blow for 45 min. each, and are then relieved by another two for an equal period. It thus takes four men to provide the blast. In addition to the furnace-man there is a charger attending to the feed. The rate paid per 16 kg. of ore treated are: Furnace-man, 12 cents (Mex.); blowers and charger, 8 cents (Mex.).

The following data pertaining to results from various classes of ore were supplied by the owner of the furnace:

Metal de correa, ó nacar (a black kidney-ore, evidently very impure). Smelting 150 kg., plus 50 kg. *plomillo* (rich slag), yields 50 kg. tin and 75 kg. *plomillo*, using 2 of charcoal to 1 of ore.

Reventón (good quality kidney-ore, the best the district affords). Smelting 150 kg., plus 100 kg. *plomillo*, yields 100 kg. tin and 50 kg. *plomillo*, using 2 of charcoal to 1 of ore.

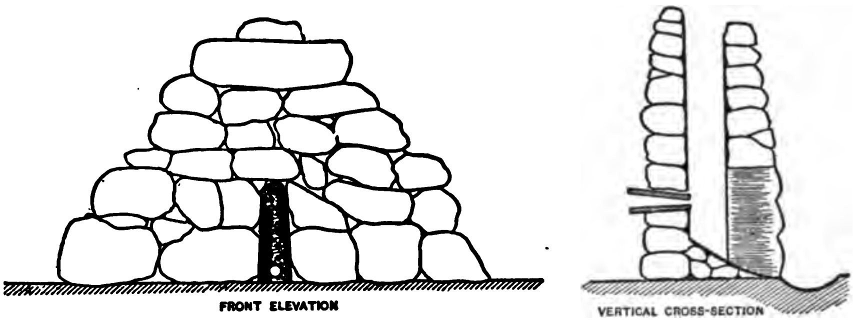
Espesa (a crystalline mixture of tin and iron). Smelting 150 kg., plus 20 kg. *plomillo*, yields 10 kg. tin and an undetermined quantity of *plomillo*, using 3 of charcoal to 1 of ore.

Fig. 26. — Mexican Tin-smelting Furnace

A sample of concentrates from the Queensland mill, near Santa Barbara, known to run about 15 per cent. of metallic tin by wet analysis, and weighing 100 kg., was washed in a batea down to 50 kg. and smelted in this furnace. It required 6 hours to run 50 kg. of concentrates, including re-melting

of slags, with a charcoal consumption of 100 kg. The produce was 1.4 kg. of tin and 8.5 kg. of impure tin, hard-head and dirty slags. Probably if further treated the recovery in clean tin would have been about 5 kg., with a loss of 9 kg. on the original content of 15 kg. The furnace and washing-losses were therefore about 60 per cent. of the total tin in the ore. The cost of smelting 50 kg. was $5.94 (Mex.).

A somewhat similar furnace has been figured and described by W. R. Ingalls * at Durango; he mentions two furnaces, one 5 feet high, 6 by 9 inches at the top and 9 by 9 inches at the tuyere, 3½ feet from the top, and another 9 by 7½ inches at the top and and 6 by 7 inches at the tuyere,



Scale, 1 in. = 4 ft.
FIG. 27. — Mexican Tin-smelting Furnace

which was 3 feet from the top. The form of the furnace is shown in Fig. 27, the float being merely a hole in the ground lined with clay.

TIN-SMELTING IN BOLIVIA

A good deal of concentrated tinstone (barilla) is exported from Bolivia as such, but some is also smelted in the country itself in small blast furnaces, charcoal being the fuel employed. The tin thus obtained is very impure, and it is

* "The Tin Deposits of Durango, Mexico," by W. R. Ingalls, *Trans. Amer. Inst. M. E.*, Vol. XXV (1895), p. 146.

exported as crude tin, the native smelters making no attempt to refine it, the object of smelting being chiefly to save freight. It seems that no attention is paid to any treatment of the slags, so that the loss of metal is very heavy, probably quite 20%.

In Potosi * ore containing 30 to 40% of tin is smelted in water-jacket furnaces 1 meter in diameter and 6 meters in height, using charcoal as fuel and a little lime as flux. When working on 33% ore, such a furnace will smelt 6 tons of ore in 24 hours, producing 35 cwt. of tin bars assaying 92% of tin, the remainder being chiefly antimony and lead; the slag produced assays about 8% of tin. The daily cost sheet of such a furnace is as follows, taking exchange at 12.50 Bolivians to £1:

Labor	£ 6. 8. 0
Supplies	2. 8. 0
Charcoal (5 tons at £6.8 per ton)	32. 0. 0
Lime (7 cwt. at £6.8 per ton)	2. 4.10
Fuel for power, etc.	7. 4. 0
General expenses	7.10. 5
Total per 24 hours	£57.15. 3
Total smelting cost per ton of ore	£ 9.12. 6
Total smelting cost per ton of tin	£33.

or, say, about $7 U. S. A. currency per 100 lbs. of tin.

The smelting cost is stated to generally reach about £12 per short ton per ton of ore, and the cost of the tin, including the value of the ore, comes to about £78 per ton at the mines.

TIN-SMELTING IN NIGERIA

In Nigeria the ore is smelted for the most part by the natives in primitive furnaces; some is smelted at the mines in the western part of the province of Bauchi, Northern Nigeria,† in a small cupola, smelting about 6 cwt. per day; the blast is produced by a Root's blower, the fuel is charcoal and the flux iron ore.

A certain amount of information is contained in a paper

* Georg Hohagen, *The Mineral Industry*, Vol. XVI, 1907, p. 878.

† *The Mineral Industry*, Vol. XVI, 1907, p. 870.

in the *Bulletin of the Imperial Institute*, 1907, Vol V, No. 2, p. 179, referring particularly to the alluvial tinstone deposits of the province of Bauchi; the washed black tin contains from 60 to 65% of metal, the chief impurities being ilmenite and garnet. For some years it has been known that the natives of this region smelted tin, the metal being sold in the local markets in the form of rods, 1 foot to 2 feet long and about $\frac{1}{8}$ inch in diameter; it was always very pure. A description of the method of smelting employed by the Hausa natives is given as follows by Mr. Nicholaus:*

"The 'black tin' is usually smelted in various parcels on a royalty basis exclusively by members of one family, who hold the process a great secret. Only three smelting furnaces are in use, and these are each capable of turning out about 2 cwt. of metal per day. They are built of well-puddled clay, and are 3 feet 6 inches in diameter, and have at the back four tuyere holes conducting the blast from primitive sheepskin bellows to the hearth. The tin is reduced by means of charcoal, and runs through a channel 2 feet 6 inches long and 4 inches broad into a catch pot, whence it is ladled by small gourds or calabashes and poured.

"The tin is cast in the form of thin bars of about one-eighth inch diameter and 12 inches long, which are produced by pouring the molten metal on semicircular banks of clay, 18 inches high, perforated by dry guinea corn halms."

Rods of tin produced by some native method of smelting, quite similar to those from Nigeria, were imported into Great Britain some 30 years ago from the Himalayan regions.

The following is an analysis of a sample of native Nigerian metallic tin, kindly communicated by the Director of the Imperial Institute:

*Op. cit., p. 182.

Sn	97.39%
Fe	2.46%
Insoluble Residue	0.16%
	100.01%

The striking resemblance between the primitive methods of smelting employed in the Far East, in Mexico, on the West Coast of Africa, and probably originally also in Europe, is remarkable, and shows that similar conditions will lead to the employment of similar smelting methods, for it is plainly impossible that these processes could have had a common origin.

There is much to be said in favor of the method of smelting in the blast furnace, provided that suitable ores and fuel are obtainable, and it seems to-day an open question whether the water-jacket furnace, properly handled, might not do at least as good work as the reverberatory furnace in ore-smelting, while for slag-smelting there seems to be actually some evidence of its superiority.

CHAPTER IV

SMELTING IN REVERBERATORY FURNACES

IN this process the ore, mixed with some reducing agent, is spread on the bed of a reverberatory furnace and strongly heated; the products are impure tin, which needs refining, and slags of various kinds which generally contain more or less silicate of tin or silico-stannates and unreduced oxide of tin, together with mechanically intermixed prills of metal; the slags have to be cleaned by mechanical or physical treatment combined with a special slag-smelting. Two methods of reduction may be distinguished, namely, true reduction by means of carbon or some carbonaceous substance, and precipitation by means of scrap iron or some ferriferous substance; in the case of slags the former method is inoperative without the simultaneous addition of a strong base, generally lime, and even so is not complete.

The reverberatory furnace appears to have been invented in the latter half of the sixteenth century, probably on account of the increasing scarcity of charcoal, and appears to have been used in Cornwall soon after its invention, even if it did not actually originate there. It is at any rate certain that the reverberatory furnace was first employed for the reduction of tin ore in Cornwall, whence its use has spread to all parts of the world, so that all existing methods are, strictly speaking, only variations of the original Cornish method. This was, however, a pure carbon reduction process, the iron precipitation process being a very recent innovation. As typical of primitive reverberatory furnace practice, it will be advisable to commence by quoting Pryce's* description (slightly condensed) of the

* *Op. cit.*, pp. 273–282.

original process, as carried on in Cornwall over a century ago, and then to investigate the various modifications it has undergone in recent times. Pryce gives no drawings or description of the furnace beyond saying that it differs little from that used in smelting copper except that it is not quite so deep; he figures the copper-smelting furnace, and gives its outside dimensions as 18 feet long, 12 feet broad, and 9½ feet high, the inside dimensions of the bed, length 7 feet 10 inches, breadth 4 feet 8 inches, and average height 2 feet, and those of the fire-place, 2 feet 8 inches long and 2 feet wide. He proceeds to describe the process as follows:

"The charge for one of these furnaces is from five to six hundredweight of Black Tin, well mixed with a tenth or a twelfth its weight of culm (*i.e.*, pounded anthracite). This furnace is charged through a hole in the side (directly opposite to the tap-hole), through which it is thrown into the furnace with a shovel, and levelled over the bottom with an iron rake or paddle from the mouth. This done, the apertures are immediately closed, and the fire raised to a very great strength, in which state it is left between four and five hours, when the door is taken off and the whole charge is well stirred together. The foreman of the work at this time examines the state of the Metal, etc., and, if he thinks it convenient, orders an additional quantity of culm, at his discretion, to be put into the furnace, which is closed again and left in this condition, the fire all the time being kept fully up, till the end of about six hours from its receiving the charge; at which time it is again examined by the foreman, and, if he finds it proper, is then tapped and the Metal let out into a fixed bason made of clay, and of a capacity to hold something more than the Metal of the charge: as in some sorts of Tin, the scoria being vitrified to a considerable degree, part thereof will flow out with the Metal, but this is not commonly the case in any large quantity. The scoria remaining in the bottom of the furnace is raked out at the mouth, and falls into a small pit under it made for

the purpose, and has generally adhesion enough to form into a cake. As soon as it is cold it is carried to the stamping mill in order to separate the globules of melted Tin (called 'Pillion') disseminated through the scoria or slag. Of the pillion so separated, all the rough or grainy parts are considered as Metal, and refined accordingly by being smelted without any flux, and the produce of this smelting refined with the Tin first tapped. The Tin in the bason, or float, as it is called, as soon as it is come down to a moderate heat, is ladled out into the moulds, in slabs or pigs of about three-quarters of an hundredweight; not larger, because they would be too unwieldy to heave into the furnace for refining. The furnace having, by the side of the small float just now described, a larger one capable of holding twenty or more blocks, is for this purpose suffered to cool to a certain degree, and then charged full with the slabs just mentioned, the tap-hole being kept open, so that as the Tin melts in this moderate fire, it makes its exit through it into the float, where while running out it is frequently stirred and tossed by a ladleful at a time held arm high, letting it fall in a stream into the mass of Metal, when the scum which arises is taken off. While the Metal already put into the furnace is melting, more is added, so as to be just enough to fill the float with good Tin, and this, after being tossed and skimmed as before, and suffered to cool to a proper temper, is carried in iron ladles to moulds holding generally somewhat above three hundredweight (then denominated Block Tin).

"There yet remains in the furnace the drossy part with which the Tin was contaminated, and which, not melting with the slow fire made use of, holds with it a considerable portion of good Tin. The fire is, therefore, now increased, so as to melt the whole; which is then tapped out altogether into the small float, where the Tin subsiding, and the dross rising to the top, the latter, soon cooling, is taken off and set by, and the Tin ladled into small slabs as at first to be again refined. The furnace is now charged again as before; and after cleansing again is generally employed to smelt

Tin Ore as usual. The Tin that remains in and about the scoria and dross of the last tappings, etc., is recovered by repeated smeltings, till at last, being almost entirely drained of that Metal, they become what the workmen generally call Hardheads, consisting of such heterogeneous metals as were included in the first mixture, and esteemed of no further value."

This is a very minute description of this process of tin-smelting and includes all the essential points; in its general outlines it might stand for a description of the operation as practised today. Pryce gives no idea of the cost of smelting, except incidentally. He describes the method of purchase of tin ore as being by promissory notes or warrants for the amount of white tin that the parcel is calculated to produce by assay, less the smelting and incidental charges and the smelter's profit, and in an example he puts the produce of 20 cwt. of tin ore at 12 cwt. of white tin and reckons that the smelter would give a promissory note or "tin bill" for 11 cwt. In other words, the smelter would charge the value of 1 cwt. of tin, or about £3 10*s*., for smelting one ton of tin ore. It is worth mentioning that the method of assay here referred to is the Cornish method, which, as has already been pointed out, is still in use to-day in Cornwall. It is of course well known that this method is decidedly inaccurate and generally gives results several per cent. below the true percentage of metal in the ore.

A Cornish tin-smelting furnace of the most modern* type is shown in Figs. 28 to 31 in full detail. The tools used in working it are repesented in Fig. 32, and the various moulds, into which the tin is cast, in Fig. 33. The dimensions vary somewhat at different works, but may be averaged as follows: Bed, 16 to 18 feet long, 8 to 12 feet wide; fire-bridge, 6 feet long by 2 feet wide, 3 feet deep below the fire-arch, and 15 inches above the bed. The bed is built over a hollow vault, and together with the fire-bridge,

* I am indebted to Mr. W. H. Borlase, of Penrith, for much valuable information concerning the modern Cornish process. — H. L.

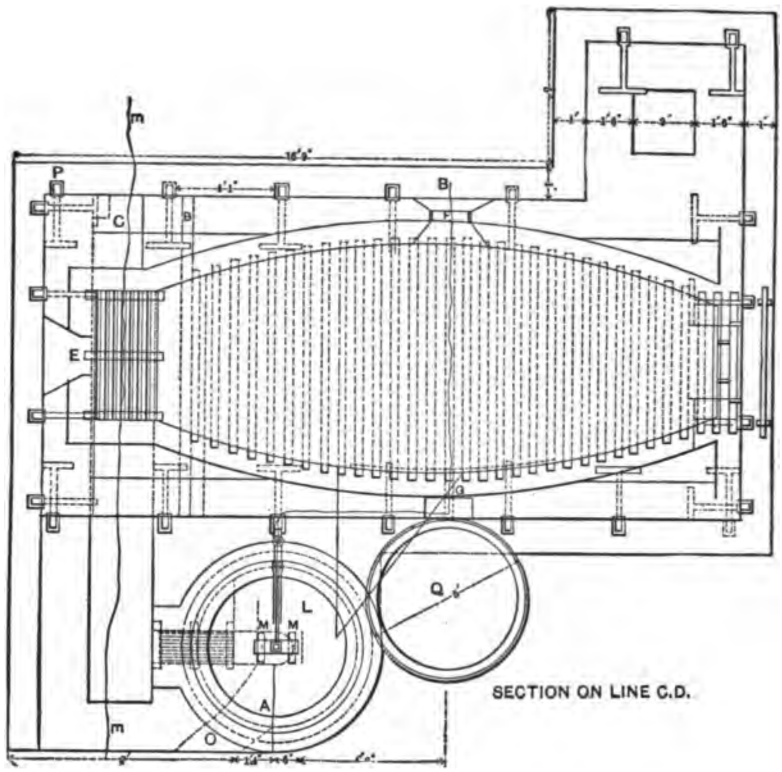


FIG. 28. — Sectional Plan of Modern Cornish Reverberatory Furnace

REFERENCES TO FIGS. 28 TO 31

A — Arch of fire-brick built on the edge, *i.e.*, two rows of 4½-in. brick work.
B — Air hole to keep bottom of furnace cool.
C — Air hole for cooling outside of fire-place.
D — Wrought-iron plate, 6 × ½ in., built at each side of furnace for strengthening arch.
E — Opening to fire-place.
F — Charging or feeding door; to be stopped with brick slab the same as H.
G — Discharge hole.
H — Working-door.
I — Fire-place of refining kettle.
J — Wrought-iron frame used for resting rake on when working through H.
K — Pan to catch any metal that may leak through the furnace.
L — Refining kettle (cast iron).
M — Wrought-iron hoops through which is held a piece of fir-wood and sunk in the molten lead by the cast weight on N.
N — Wrought-iron hinged crane; the perpendicular bar and weight pulled up by a small pulley block high enough for hoops to pass from kettle L.
O — Flue from refining kettle fire to pass off in any convenient place and to any ordinary house chimney.
P — Cast-iron bars for binding furnace, held at the bottom by strong wrought-iron eyes built in the masonry.
Q — Wrought-iron float lined with fire-clay to take metal from discharge hole.
R — Bed built of single brick on the flat to catch any metal that may leak through furnace.

which is also hollow, is cooled by allowing air to circulate underneath it, air-holes being provided in the brickwork of the sides. The bed is carried upon transverse iron bars,

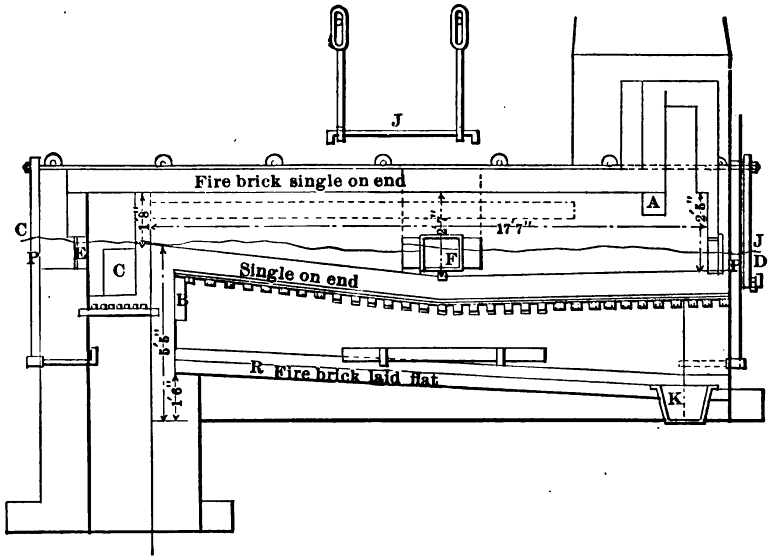


FIG. 29. — Longitudinal Section on Center Line of Furnace

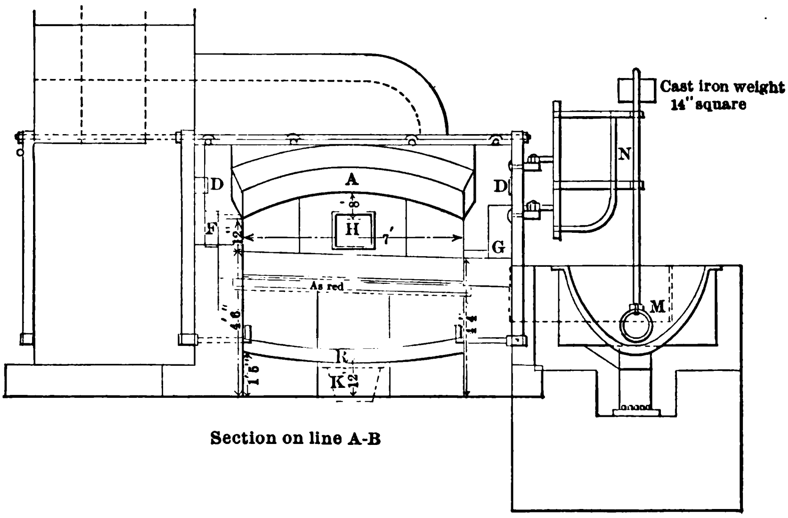


FIG. 30. — Transverse Section of Furnace

upon which rest slabs of slate, or more rarely fire-clay tiles; these are covered by a bed of clay from 6 to 9 inches deep, upon which rests the bed proper, consisting of good sound fire-brick, laid on end, close together, and well grouted in. Such a bed lasts in ordinary working for about three months, and then requires renewal, an operation that takes about two days. Below the bed, just about the ground level, is

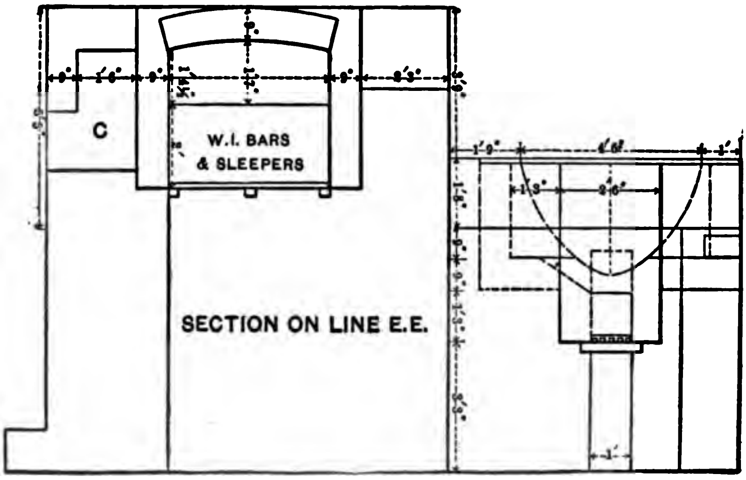


Fig. 31.—Transverse Section of Furnace at Fire-place

a floor of fire-brick laid on their broad sides, sloping towards an iron pan, into which any tin that may have leaked through the bed proper trickles, and from which it can be ladled out from time to time. The bed itself is shallow, having a "dish" of about 6 inches, and sloping from every side towards the discharge or tap-hole. In front of the tap-hole is the cast-iron float, and close to the latter is a second larger float or refining kettle, set over a small independent fire-place provided with a small flue. Opposite to the tap-hole is the charging or feeding door that can be tightly closed by a fire-brick quarry, and at the flue-end of the furnace is the working-door, or viewing-door, provided usually with an iron roller, to facilitate the use of the rakes, rabbles, and other tools, and also capable of being closed with a quarry.

The fire-door is opposite to the last-named door and is placed pretty high up; this is only an opening, not a door properly speaking, and is kept closed by the "green" coal while the furnace is at work. A clinker-bed is used, and

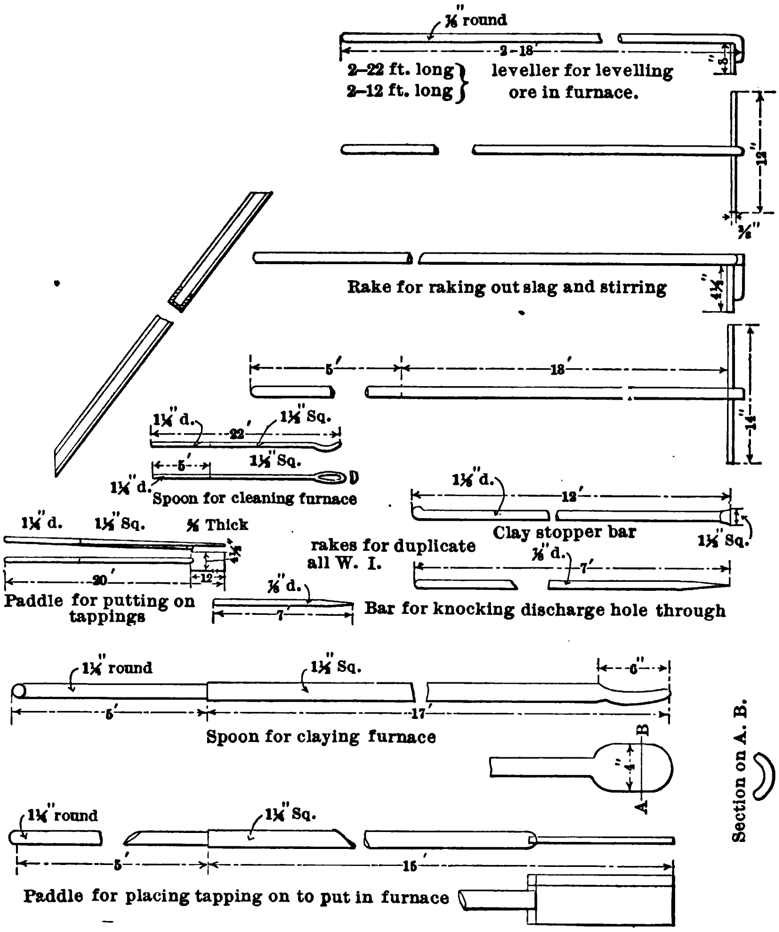


FIG. 32. — Tools Used in Working Cornish Furnace

the fire-place is kept full of coal almost up to the level of the fire-bridge. It some of the older forms there was another door in the crown of the fire-arch, kept always closed by means of a fire-brick slab, except during charging, when it was opened, so as to diminish the draft over the bed and

thus prevent fine ore from being carried off; the same object is now attained by closing the damper during charging. Each furnace has its own stack, about 50 feet high, fitted with a damper; dust chambers are not used. The furnace is held together in the usual way by iron plates, buck-staves and tie-bars.

The cost of such a furnace is about £160, of which £90 are for bricks, mortar, iron work, etc., and £70 for labor. The cost of the chimney and flues, everything included, is about £250.

The smelting charge for these furnaces varies in different works from 2,700 pounds to 3 tons, 2 tons being about the average. In the most important Cornish works at Penzance, 2-ton charges are smelted, four charges being worked off in 24 hours; at another works, 3-ton charges, of which three can be got out in 24 hours, are preferred.

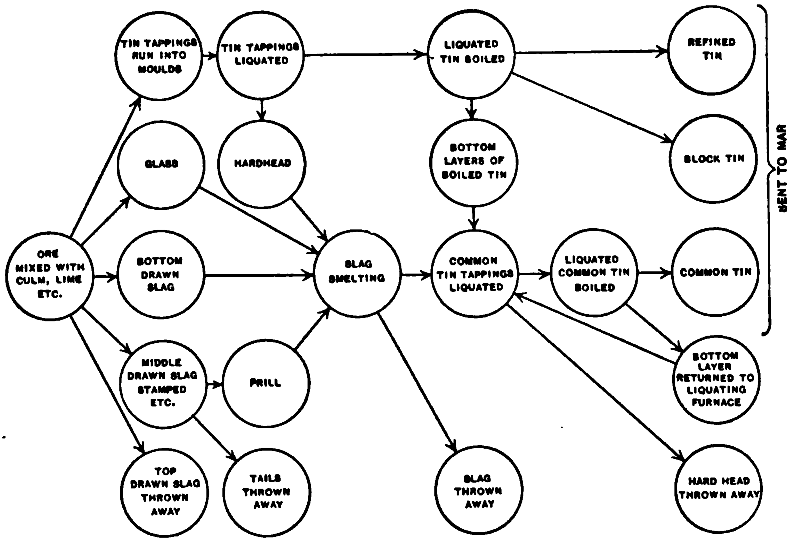
The ores treated are chiefly Cornish and Bolivian. The former, after being properly dressed, generally contain 62 to 65% of metal (equal to 79 to 82% SnO_2), the remainder consisting of silicious matter, 5 or 6% of oxide of iron and small amounts of tungstic acid and other impurities. Bolivian ores are generally richer, containing up to 72% of metal (92% of SnO_2), 5 to 6% of silicious matter, and 1 to 3% of oxide of iron, etc.

The charge consists of ore mixed with 15 to 20% of culm — spoken of, though incorrectly, as "flux" by the smelters — together with a small amount of slaked lime in varying proportion according to the quality of the ore, occasionally some slag or other tin-bearing products from previous operations, and at times a little fluorspar. These substances are thoroughly mixed and well damped with water. The charge is wheeled to the furnace in barrows, and tipped on the ground in front of the charging-door. The furnace being all clean after the previous charge has been got out, any weak spots in the bed having been clayed up, and a good heat raised, the charge is shovelled in and spread smoothly over the bed by means of a rabble worked

from the end-door. Both doors are then closed tightly and may be luted with fire-clay, and a full fire is put on. After from one to three hours the mass should be fairly well melted; it is then rabbled through, the fire being kept up all the time, and rabbling is repeated at intervals as judged necessary. In from 5 to 7 hours the operation is usually completed, the temperature being about the melting point of cast iron. The mass is again well rabbled through and allowed to settle, so that the metal may separate as completely as possible from the slag. The slag is then drawn out through the working-door, by means of rakes or rabbles, and if it appears too thin it is thickened by a few shovelfuls of culm; it is known as "pulled slag." The top layer of slag that is first drawn off (about two-thirds of the whole) is generally considered clean and not to be worth further treatment. The next lot contains a good deal of tin in the form of shot or prill, and is sent to the stamps to be crushed and washed, old furnace beds or other residues being treated in the same way. The remainder of the slag requires to be re-smelted together with the prill obtained by the treatment of the previous lot. Not all the slag is obtained in the form of pulled slag; a certain amount remains on the metal in a molten condition and runs out with it into the float when the furnace is tapped; it rises to the top and forms a layer on the tin in the float, and is removed as soon as it has set. This slag is known as "glass" and has also to be re-smelted. The tap-hole is always closed during the smelting operation by means of an iron bar of about $1\frac{1}{8}$ inches in diameter, known as the "clay stopper bar," which is clayed into its place. After as much slag as is possible has been drawn out, this bar is pulled out and the tin runs into the float together with a certain amount of glass. In order to clear out the furnace, the whole of the clay stopping is finally cut out by means of a pointed bar. After the glass has been removed, the tin is allowed to stand for some hours; any dross that forms on the surface is skimmed off, and put aside for retreatment, and the metal is ladled into moulds

holding about 100 pounds, the flat slabs so produced, known as "tappings," being then ready for refining.

The subjoined scheme shows diagrammatically the general course of smelting operations when ores of fairly good quality are being worked, but variations from it are very often made.



At Penzance four furnaces are worked by 16 men all told, there being eight furnace-men who work 12-hour shifts. There are only the four furnace-men and one helper or tender on the night shift; two charges are worked every shift. The consumption of coal in smelting is about one ton of coal to the ton of ore.

Refining is carried out either in a smelting furnace in some of the smaller works, or else in a special refining furnace, with a flat bed sloping uniformly toward the tap-hole; outside the latter stands a large cast-iron float that can be heated by means of a small fire-grate below it. The slabs of tin are charged by means of a peal or paddle (see Fig. 32), and are laid close together on the upper parts of the bed, and a small fire is put on, so that the tin melts at a gentle heat

and trickles through the open tap-hole into the float, leaving the more infusible impurities on the bed; these are drawn aside and fresh slabs are charged in, until the float, which holds from 6 to 10 tons, is full. The tap-hole is then closed and the fire raised until the residue left in the furnace is melted; this is run off into another float where it is allowed to settle, and after a time separates into two portions, the upper and more fusible being an impure tin which is ladled out into moulds. This tin requires special refining. The

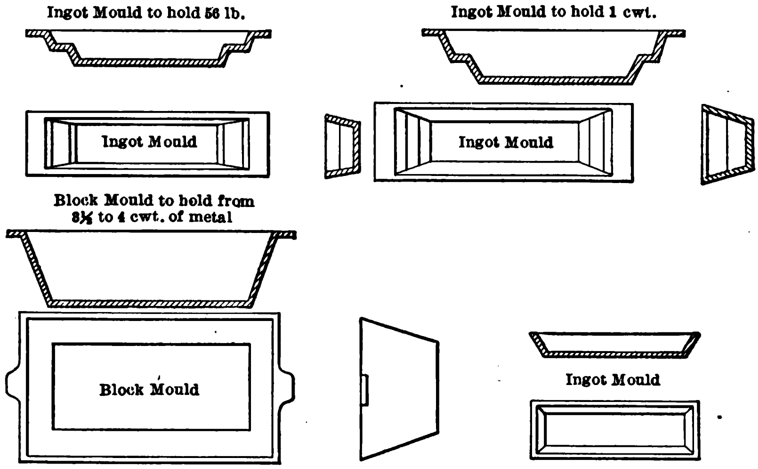
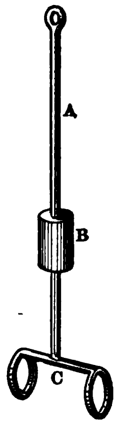


Fig. 33. — Block and Ingot Moulds Used in Cornwall

residual hardhead which generally adheres to the sides and bottom of the float is then removed; it is rarely considered worth further treatment and may be added to the charge in slag-melting or may be sold.

Meanwhile, the molten tin in the float, having been allowed to settle, is skimmed, and then boiled; the latter operation is performed by forcing into the metal a number of billets of green wood held in a cage and weighted down so as to force the wood well below the surface of the molten metal. The construction of one of the most usual forms of cage is shown in Fig. 34; *A* is an iron shank 6 to 10 feet long, upon which is fixed the cast-iron weight *B;* billets of green

wood, which may not, however, be wet, are placed in the two hoops composing the cage *C*, and the whole apparatus is suspended by a rope or chain running over a pulley above the float, so that it can be lowered when required, the weight *B* forcing the wood down to the bottom of the float; another form is shown attached to the furnace in Fig. 30. A dense wood, like apple-wood, which evolves gases at a comparatively slow rate, is generally preferred, though firwood is at times used. The chemistry of the process is not yet completely understood. The wood is slowly distilled by the action of the molten metal, and the gases evolved, together with the steam given off, keep the bath in a state of violent agitation, throwing up spurts of tin that fall back into the bath; a large surface is thus constantly exposed to the air, and it seems probable that the oxygen of the latter, by oxidizing the impurities present, plays the chief part in the operation of refining by boiling. A scum forms on the surface of the tin, which seems to consist of oxides of the various metals present, together with a certain amount of finely divided metal; it is skimmed off and subsequently re-smelted with slags, etc. The operation of boiling takes about 3 hours, liquating occupying 1 to 2 hours. After the boiling is finished the tin is allowed to stand at rest for an hour or two, in order that all the heavier impurities still present may settle to the bottom of the float. The tin is then ladled into moulds; the uppermost or purest portion is known as refined tin, the next, which is still sufficiently pure for many commercial purposes, is called block tin, and the remainder, which is not marketable, has to be refined over again.



A, shank; B, weight; C, Cage. Scale: 1″ = 6′

FIG. 34. — Perspective View of Boil Cage

Refined tin is usually cast in ingots varying from 7 to 100 pounds in weight, or sometimes into bars or strips of from 3 to 5 to the pound. Block tin, which is largely used

in the manufacture of tin-plate, is cast in big blocks weighing 350 to 400 pounds. The various forms of moulds used are shown in Fig. 33.

Tossing is sometimes substituted for boiling, the metal being dipped out in ladles holding about 30 pounds and poured back into the bath from a height of 2 or 3 feet. It is hard work for the men, and appears to present no advantage over boiling.

It must not be forgotten that the refining of tin is at the best an imperfect operation, and that large quantities of impurities cannot be separated by it. The quality of the tin ultimately produced depends therefore very largely upon the purity of the ore charged into the smelting furnace, and it is therefore imperative that any impurities present originally in the ore should be removed as completely as possible in the preliminary operations of roasting, dressing, etc., sc that the smelter may receive the ore in the highest practicable state of purity.

The following analyses show the average composition of English tin:*

	%	%	%
Sn	99.76	98.64	99.73
Fe	Trace.	Trace	0.13
Pb	—	0.20	—
Cu	0.24	1.16	Trace
Totals	100.00	100.00	99.86

Analyses of the various slags are not obtainable. The following is the analysis of a molten slag or glass from a Cornish furnace according to Beringer:

* Schnabel, *Metallhüttenkunde,* II, p. 432.

SiO_2	39.4
Wo_3	1.3
SnO	8.1
FeO	26.2
MnO	Trace
Al_2O_3	14.8
CaO	7.9
MgO	0.5
Alkalies (Na_2O)	1.7
	99.9

Berthier found 13.02% of tin in a slag free from prill, that was thrown away. He also gives the following analysis of a slag produced at Poullaouen in France in reverberatory furnace smelting:

SiO_2	40.0%
SnO_2	8.4%
FeO	20.3%
MnO	11.1%
CaO	3.6%
MgO	1.0%
Al_2O_3	9.6%
Total	94.0%

It is generally considered that slag with about 5% of tin is no longer smeltable with profit in Cornwall. At present a good deal of Cornish tin slag is shipped to Wales and there sold; it is said to be treated by being smelted (in cupola furnaces) with oxidized lead residues and residues from tin-plate works, the result being an alloy of lead and tin that is marketable as such, and a slag practically free from tin. Hardhead was long looked upon as an unmarketable commodity, and the tin it contains was looked upon as lost. Of late years, however, this tin has been recovered by smelting the hardhead with galena or with antimony ore, producing an alloy of tin with lead or antimony, which can be used as such for making alloys, whilst the slags obtained are practically free from tin.

It is usually stated that the loss in the Cornish method of smelting is about 9%, a certain amount of which is said to be recovered when the furnaces are taken down for

repairs, because tin is so readily fusible, and so mobile when melted, that it readily percolates through any cracks or joints in the beds, and finds its way into the foundations of the furnace. As a matter of fact, however, no one except the smelters themselves, and possibly not even they, know accurately what the losses in tin-smelting are. Much of the difficulty arises from the barbarous method still employed for buying and selling the ores. At the fortnightly ticketings the buyers obtain samples of the various lots of ore for sale, and assay them, and then send in their bids at so much per unit, *i.e.*, the price they give nominally per ton for each per cent. of gross tin in the ore, the highest bidder of course securing the parcel. Unfortunately, however, both assays and weights are misleading; the assay is the old inaccurate Cornish assay and the weights used are not statute weights, but the ton consists of 20 cwt. of 115 pounds each, while "draftage" is allowed at the rate of 1 pound in each cwt., 2 pounds in 7 cwt., 3 pounds in 8 cwt., and so on, and moisture is allowed for at the rate of $1\frac{5}{8}$ cwt. to the ton of ore, or $8\frac{1}{8}\%$; besides this the smelter deducts an amount that he considers will cover the cost of smelting; he thus gets a great deal more tin apparently than he pays for on the face of the figures returned. It would be difficult to say much in defense of this system of dealing; the usual Cornish argument that this was the method practised by their ancestors is hardly satisfactory. No doubt an accurate assay showing the real tin contents of the ore would be better in the interests of both buyer and seller, and would go far to remove any suspicion that one party is obtaining an unfair advantage over the other. Moreover, correct assays would necessarily force upon the smelters a recognition of the amount of tin that they are really losing, and this, the inevitable first step toward a general improvement of the process of treatment, would assuredly benefit the entire tin trade.

Nothing is accurately known as to the cost of smelting; the consumption of fuel, excluding the culm used for

reduction, is usually given as 30 to 35 cwt. of coal to the ton of tin. In 1895* the total amount of tin ore produced in Great Britain was 10,612 tons, of an average assay value of about 60 to 65%; the price it brought at the mines was £370,530; this ore is estimated to contain 6,648 tons of metal, worth at block-tin price in London £446,780, so that the difference of £76,250, or over £7 per ton of ore, represents loss in smelting and the cost of smelting plus smelters' profits less a small amount for carriage to London and agents' commission. In addition to British ore, a certain amount of foreign ore is smelted; the imports in 1895 were 4,705 tons, of which by far the largest part was Bolivian ore; of this 3,830 tons was imported direct, while it is probable that nearly the whole of the ore imported from Germany and other European ports, amounting to about another 500 tons, came originally from the same source. All the Cornish and imported ores were smelted by seven firms of smelters in the south of England, the works of five being situated in Cornwall, one in Devonshire, and one at Bristol.

In addition to these, smelting operations have also been commenced near St. Helens, Lancashire, where Bolivian ores are being treated. The process is practically the Cornish process, but many details have been modified and improved, all these alterations being kept rigidly secret. The smelting and refining furnaces are practically identical with those shown in Figs. 35 and 36; the former is an ordinary Cornish furnace, a good example of the usual though not the most modern type, but the latter is essentially novel in design, consisting of two cast-iron trays inclined in opposite directions, each toward a float of its own, set over a small fire, on opposite sides of the refining furnace. This arrangement is said to produce a marked economy of fuel consumption.

In 1909† the production was 8,289 tons of ore, valued

* *Mineral Statistics of the United Kingdom for* 1895, p. 163.

† Mines and Quarries. General Report and Statistics for 1909. Part III. Output (*Caption, Tin*).

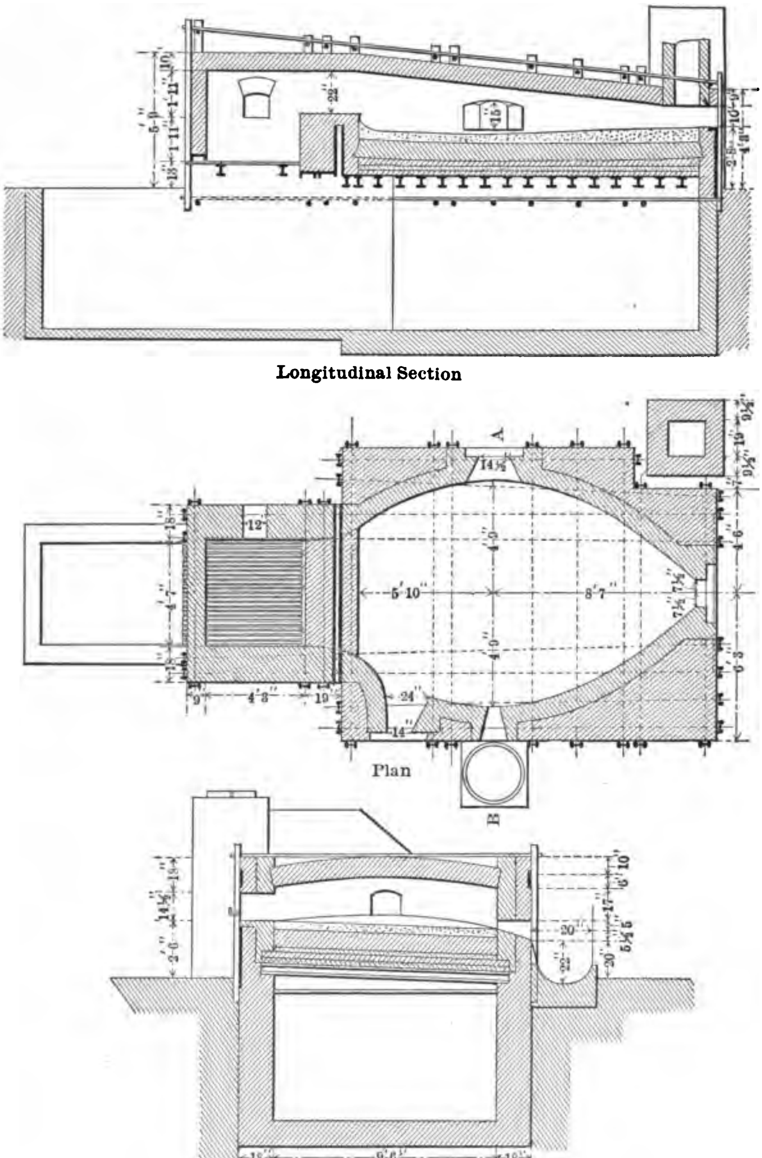


FIG. 35. — Tin-smelting Furnace built for the Almaraz Tin Mining Co., Spain

at £617,376 at the mines, assaying on the average 62.6%; this ore is estimated to contain 5,193 tons of metallic tin, worth at the year's average block-tin price in London £694,710, giving a difference of £77,334, equal to no less than £9.6.8 per ton of ore. As the quantity of tin smelted

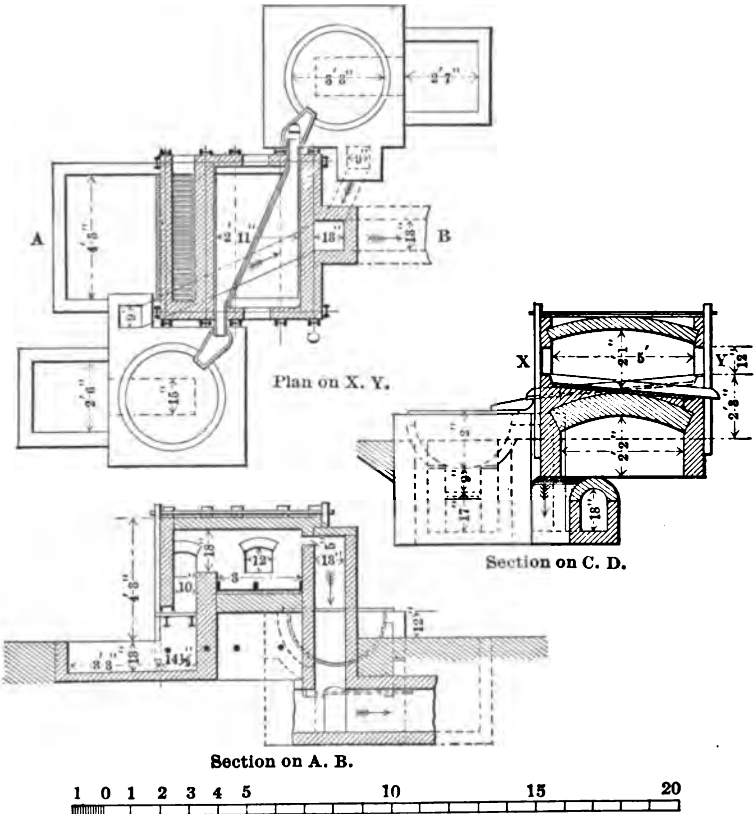


FIG. 36. — Tin-refining Furnace

was over 2,000 tons less than it was in 1895, and as the loss of tin in smelting and the cost of smelting have both probably decreased (or certainly ought to have decreased, as they have in the smelting of all other metals) since 1896, it is clear that the smelters' profits have increased considerably. There has been a large increase in the impor-

tation of ore from abroad, the importation in 1909 having been 24,086 tons of tin ore valued at £1,621,175 in addition to 41,725 tons of metal valued at £5,603,844; a certain proportion of this was, however, for re-export. The ore came chiefly from Bolivia (from Bolivia direct 14,886 tons, from Chile 3,372 tons), with smaller quantities from the Transvaal (2,611 tons), Australia (318 tons), Nigeria (259 tons), Spain (227 tons). The bulk of the metal imported came from the Straits Settlements (36,084 tons), other importers being Australia (4,674 tons) and Bolivia (810 tons). It may be noted that the average price in London of English block tin was £133.15.8, and of English refined tin £135.14.9 per ton. Tin-smelting was carried on to a greater or less extent by some 15 firms, the chief ones being in Cornwall (6), Glamorganshire (2), Bootle near Liverpool (2), Bristol (1).

On the Continent of Europe the reverberatory furnace process is only in operation at one works at the present time, namely at those of Messrs. Robinson & Bense, at Tostedt, near Hamburg, which have been steadily increased until their present capacity is 5,000 tons of ore or about 2,500 tons of metallic tin per annum.

The ores treated are practically all Bolivian ores, small parcels of other ores being at times, though rarely, purchased by the firm. It is worthy of note that the situation of the works, at first sight apparently quite unsuited to their purpose, in reality presents many advantages. Although remote from the centers of production of either the ore or the fuel, the works nevertheless lie on the great trunk line that connects the important seaports of Hamburg and Bremen with the coal fields of Westphalia; coal can thus be brought readily and cheaply to the works under the differential rates granted by the German Government, so that, although German coal is inferior in quality to imported Welsh coal, it is found more economical to obtain fuel from the German coal fields. The ores treated are imported through Hamburg or Bremen, and the metal produced is easily forwarded

to market at home or abroad by rail or sea. Messrs. Robertson & Bense buy through their local agents from 4,000 to 5,000 tons of Bolivian ore a year, which constitutes no inconsiderable proportion of the entire annual ore output of that country. These Bolivian concentrates known as "barilla" vary greatly in character, and contain many impurities, such as bismuth, lead, copper, antimony, arsenic, sulphur, etc.; they are usually of low grade, carrying 40 to 60% Sn, 10 to 30% SiO_2, and up to 10% Fe. The ores arrive in bags containing about 1 cwt. each, which when delivered to the works are opened and examined, sampled, assayed, and very carefully classed according to their qualities.

Each batch of ore, if not already in fine powder, is ground in a ball mill. The ground ore is then charged into the roasting furnaces and calcined until perfectly sweet. There are three reverberatory roasting furnaces, of the "Fortschaufelungsofen" type; one has two hearths, and the remaining two have four hearths each; the hearths of the latter, which are of newer construction, are carried on iron rails so as to be easily accessible for repairs. The smaller furnaces calcine from 2.5 to 4 tons, the larger from 5 to 10 tons of ore per 24 hours, the amount put through varying with the percentage of sulphur present. Great stress is laid upon the thoroughness of the calcination, the object being to remove all sulphur entirely, together with as much arsenic as possible. The ore when thoroughly calcined is drawn out onto the floor in front of the furnace, where it is allowed to cool. It is then wheeled to the smelting furnace where the charges are mixed; these consist of the roasted ore together with 15 to 20% of finely ground anthracite and lime, the amount of the latter being 50% more than that required to flux the silica in the ore, the composition of slag aimed at being a neutral silicate.

The smelting furnaces are of the usual reverberatory type with working-doors at the front and side. In the most recent form, the entire furnace is carried upon iron girders

supported upon cast-iron pillars set in rectangular brick-lined pits about 5 feet deep, and is thus entirely free from the floor. The hearth proper is carried on iron rails. The workmen thus have free access through the ashpit to the space beneath the bed and can easily remove and collect any tin that may trickle through the hearth or through the masonry of the furnace. The air space beneath the furnace is kept well ventilated. The bottom is made of brick, upon which is burnt the working bottom proper, made of sand. This sand bottom is dished out and slopes in the usual way toward the tap-hole, and lasts, with occasional repairs, about one month. The maximum length of the bed is 23 feet, and its maximum width, 16 feet; its area is 300 square feet; the grate area is 28 square feet.

There are two large and two small smelting furnaces; each of the latter can treat 4 tons 5 cwt. of ore (or 4 tons 15 cwt. of slags) per 24 hours; the larger of the others can treat 6 tons 15 cwt. of ore (or 8 tons of slags), and the smaller, the dimensions of which have just been given, 5 tons 10 cwt. of ore (or 6 tons of slags) per 24 hours. It is intended to work three of the four furnaces continuously, keeping one in reserve. The average time of working a charge is from 8 to 10 hours, with a coal consumption of about 50% of the weight of the charge. The temperature is kept fairly low when smelting ore, the slag-smelting requiring a somewhat greater heat. When the charge is thoroughly melted the tin is tapped out into a cast-iron kettle and the slag is run into sand-beds. The solidified slag, containing 20 to 25% of tin, is then broken up and re-charged into the reverberatory furnace, together with about 6 to 8% of hardhead obtained from the liquating furnace; the slag charge is worked precisely like the ore charge, the products being tin of a poorer quality and slag which is sent to the blast furnace. The latter is a cupola furnace about 30 feet high and 7 feet diameter at the boshes, and has 3 tuyeres; it can smelt 20 to 24 tons of slag per 24 hours. The coke consumption is 15 to 18% of the weight of slag smelted, 6 to

10% of hardhead being also added. The resulting slags are re-smelted in this furnace once or occasionally twice before they are clean enough to be thrown away. The clean slags contain less than 5% Sn. The work-tin produced in these various smelting operations passes to the refinery, in which are two liquating furnaces having rectangular beds about 18 feet long by 8 feet wide, sloping uniformly from one side to the other, and having a fire-place at one end. The bed is divided into three compartments, and in refining the ingots of work-tin are charged at the upper edge of the central division, and the tin liquates out and runs through a tap-hole at the lower edge into moulds placed to receive it, leaving a mass of refinery residues on the bed. These residues are then transferred to the first division of the bed nearest to the fire-bridge, which is naturally the hottest; an additional amount of tin is thus obtained which is run into moulds and the resulting ingots charged into the second division, the residual hardhead being drawn out. Meanwhile all the tin that has run out of division No. 2 of the bed is placed in the third or coolest compartment and then again liquated, yielding a tin which is ready for poling, and a small amount of residues which is transferred to the second division of the bed. Each liquating furnace can treat 3 tons of work-tin in 24 hours.

There are two hemispherical cast-iron poling kettles, each holding a charge of 6.5 tons of tin, which is melted down slowly and poled in the usual way with a piece of green wood for half an hour to one hour, after which the refined metal is ladled into moulds. A kettle can treat two charges in a 12-hour shift.

The works produce three grades of tin, depending mainly upon the quality of the ores employed:

I. "Bell" tin, guaranteed to contain 99.90% of tin, and often containing up to 99.95%.

II. "Extra" tin, containing 98% of tin and about 1% each of antimony and lead, with traces of copper and iron.

III. "R. B." tin, containing 95% of tin, with varying amounts of impurities.

Owing to the large proportion of impurities, notably of iron, present in the ore treated, the production of hardhead in the course of liquation is in excess of that consumed in smelting the slags, and various processes have been devised for utilizing the considerable proportion of tin which it contains. One process consists in heating the hardhead with metallic lead, producing solders (alloys of lead and tin) of varying composition and leaving a residue mainly of iron with a small amount of tin and lead, too small to warrant further treatment. This process is quite successful technically, but the demand for alloys of lead and tin of somewhat variable composition is by no means steady.

An electro-chemical method has been tried which promises satisfactory results, although it has not as yet become perfectly practical. The slag is granulated and treated with dilute sulphuric acid heated by steam, yielding a solution of tin sulphate which is used as the electrolyte; slabs of hardhead form the anodes and sheets of tin the cathodes, and all are contained in a long rectangular tank similar to those in use for electrolytic deposition. By regulating the current strength and the strength of the solution (the latter being kept in active circulation) a firm deposit of tin can be obtained.

The Tostedt works are able to treat tin ores which are probably the worst and the most impure in the world, and yet produce a tin equal to the very best in the market; moreover they know exactly the composition of the metal produced, and can therefore say at once which of their products is by its chemical composition the best suited for any required purpose, thus representing a stage of progress far in advance of that attained by the Cornish tin smelters.

The only tin-smelting works in Germany are those in Saxony and at Tostedt; the latter started in 1891, in which year they seem to have produced 238 tons of tin, an amount

that rose to 644 tons in 1892 and 909 tons in 1893; since this small beginning the works have been repeatedly increased and improved, and now may be looked upon as works of first-class importance. The ore is imported chiefly via Hamburg, which is the chief importing port of Germany, and most of the tin ore and crude tin sent to that country passes through it; no figures as to the import of tin ore are, however, available.

Tin ores occur at various places in Brittany and have been worked there, but never with any great measure of success. Smelting works have been erected at Piriac, near the mouth of the Loire, and at La Villeder, Morbihan, reverberatory furnaces having been used in both cases, but neither are in operation now. La Villeder was worked about 1893 by an Anglo-French company, which erected dressing and smelting plant at a cost of 80,000 to 100,000 fcs. ($16,000 to $20,000); the whole concern was sold some two years later for 25,000 fcs. ($5,000). The furnace used had a bed about 11 feet long by 7 feet wide; the charge consisted of 1½ tons of ore and 600 pounds of culm, and in 24 hours 6 tons of ore were smelted with a consumption of 9 tons of fuel (coal). There is still a small quantity of tin ore (about 120 tons in 1894) imported into France and apparently worked up there, but official statistics give no return of any tin-smelting works in the country.

Spain and Portugal have produced tin ores in small quantities for many years, but have always exported them raw or smelted them in the small shaft furnaces already described. Dressing and smelting works were indeed erected by the Almaraz Tin Mining and Smelting Company, Limited, an English Company that was operating mines at Almaraz, Zamora. The works were designed and constructed by Messrs. Bowes, Scott & Western, Limited, of London, who were also the builders of the necessary furnaces. The Cornish method of smelting was to have been adopted, the furnaces being modelled upon the types of those in use in Cornwall (Figs. 28 to 31) and in Lancashire (Figs. 35 and

36). These furnaces may be considered as representing a fairly modern type of reverberatory furnace construction, although as a matter of fact the mining venture at Almaraz turned out unsatisfactorily, and the furnaces were never put into commission.

In all the Australian colonies in which tin ore is found, the Cornish method, or a variation of it, is the smelting process employed. The chief tin-smelting districts of New South Wales were Pyrmont in Sydney, and Tent Hill on the Vegetable Creek tin field, where the Glen Tin Smelting Company had works; the latter were closed down about 1895, and the ore from this district is now sent to Sydney to be smelted.[1] The ore after dressing contains about 70% of tin. There are also works at Irvinebank in Queensland, and Launceston in Tasmania, where the tin ore from the Mount Bischoff mines is smelted. Tin ore exists in Western Australia, and the government has offered a bounty of £1,000 ($5,000) for the first tin works started, but none has yet been erected. Numerous smaller works exist or have existed in various places, but the above are the most important. The methods of smelting are, generally speaking, similar, and constitute an improved Cornish process; thus while the maximum charge of the Cornish furnace was for a long time only 27 cwt., in Australia 3-ton furnaces were soon built, and an iron-precipitation process for slag-smelting was also introduced. As it was found difficult to obtain anthracite for mixing with the ore in Australia, the culm used in Cornwall was replaced by ordinary bituminous coal. At Tent Hill and Irvinebank, both of which places lie inland, and are not near any coal field, the use of wood as fuel and of charcoal as a reducing agent was introduced, very good results being thus obtained.

The Vegetable Creek tin field produces annually somewhat over 1,000 tons, having fallen off a good deal in recent years; practically the whole of this ore was at one time

[1] "The Mineral Resources of New South Wales;" Edward F. Pittman, p. 143.

smelted at the Tent Hill works. These comprise three reverberatory furnaces,* with beds 14 to 16 feet long and 6 to 8 feet wide; the fire-bridge is 1 foot high, and the height of the arch is 2 feet. The stacks are 50 to 60 feet high. The furnace bottoms are carried on iron bars so disposed as to be readily knocked out for repairs, when required. The furnace charge consists of 3 tons of dressed ore and 1 ton of charcoal moistened with water and spread over the bed to a depth of about 12 inches in the center. The composition of the ore varies according to whether it is stream tin or lode tin. The following is an analysis † of a tinstone of the former class from the Jupiter Mine, Vegetable Creek:

SnO_2	89.92%
TiO_2	0.69%
Al_2O_3	6.75%
SiO_2	0.80%
Fe_2O_3	2.30%
Total	100.46%

The furnace, as previously stated, is fired with wood; the charge is rabbled through occasionally, and at the end of 12 hours is tapped in the usual way into a large brick-lined float. The metal so produced is comparatively pure; it is ladled into a 5-ton refining kettle, where it is allowed to stand for some two hours; the upper portion is ladled into a smaller kettle where it is boiled by the immersion of billets of green "stringy bark" for four hours. It is then generally soft enough for trade purposes and is cast into 50-pound ingots; these contain 99.5 to 99.8% of pure tin. The slags and other residual products are smelted separately. The Sydney Smelting Company, the property of Mr. T. H. Kelly, refuses to give any information respecting the method of tin-smelting there practised.

The Mount Bischoff Tin Mining Company owns a smelting works at Launceston, Tasmania, where not only the

* T. W. Edgworth David: *The Geology of the Vegetable Creek Tin-Mining Field*, 1887, p. 154.

† A. Liversidge: *The Minerals of New South Wales*, 1888, p. 82.

ores raised at the Mount Bischoff mines, but most of the tin ores of the colony are smelted. The smelting plant consists of six small reverberatory furnaces,* of the ordinary Cornish type, the bed being 13 feet 3 inches long by 9 feet 6 inches maximum width. There is one stack for each pair of furnaces, and a refining kettle set close to the stack, as shown on the subjoined general plan of a pair of furnaces, Fig. 37, the right-hand one being shown in section. The ore

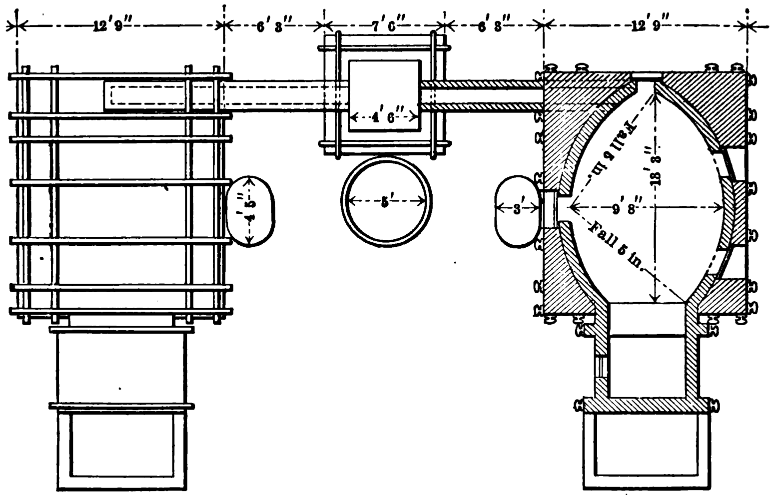


FIG. 37. — Plan of Tasmanian Tin-smelting Furnace

smelted is about two-thirds from the Mount Bischoff mines, containing 65 to 72% of metallic tin, oxide of iron being the chief impurity, and one-third alluvial ore from the east coast of Tasmania, averaging about 70% of metal, silica being the chief impurity. It is advantageous to mix these ores in smelting, since the silica tends to prevent too much of the iron of the first-named ore from being reduced and passing into the tin. The furnace charge consists of 50 cwt. of ore mixed with 10 cwt. of small coal; this is shovelled in through the two charging-doors, the skimmings, etc., from the previous refining are thrown on top of

* From information kindly supplied by Mr. L. F. Latta, smelting works manager.

the charge, and the doors are closed and luted with clay. A strong fire is put on, and the charge is examined and rabbled some three or four times. When all is well melted, the metal is tapped out into the oval brick-lined float in front of the tap-hole. The slag remaining in the furnace is strongly fired for another hour, and is then drawn out into sand-beds for further treatment, when the furnace is ready for a fresh charge. The total time of working off a charge is eight hours, and each furnace treats 40 tons of ore per week.

The metal in the float is allowed to stand for an hour, and is then ladled into the refining kettle, any unfused residue at the bottom being removed, and added to the next ore-smelting charge. When the refining kettle is full, it is "boiled" in the usual way by means of pieces of green wood and continuously skimmed; this boiling takes two to four hours, the wood being renewed whenever the ebullition shows signs of slackening. Samples are taken from time to time in the usual way, and are passed as sufficiently refined when the fracture is silky and free from cracks. The impurity most to be feared is arsenic, 1% of which is sufficient to spoil the texture of the metal; as it cannot be removed by any known process of refining, it must be got rid of before smelting by carefully roasting the ore. When the tin is sufficiently refined, the wood is withdrawn and the metal allowed to stand for awhile, after which it is cast into ingots. Any residue at the bottom of the kettle is set aside for re-treatment.

The slags contain 10 to 20% of tin; they are broken to the size of road metal, and a charge of 25 cwt., mixed with 3 to 6 cwt. of small coal and 0.5 to 1 cwt. of lime, is smelted in the same furnace as is used for ore, but at a higher temperature and for 10 hours. Slags from Mount Bischoff ore do not need any addition of iron, but slags produced entirely from alluvial ores require iron in the form of either scrap or ore to produce clean slags.

The slag metal tapped from this charge is very thick and impure, and contains a large quantity of iron; it is thrown

on top of the ore-smelting charges. The slags from the second smelting contain about 5% of tin, and can be thrown away. This apparently large percentage of tin can be reduced to 2% by a third smelting, or by adding large quantities of iron in the second smelting, but the difficulty of separating the iron from the metal produced and the injury done to the furnace render this further cleansing of the slag unprofitable. The total loss of tin amounts to 1.4 to 2% upon the ore — *e.g.*, an ore containing 72% of tin would yield from 70 to 70.6% of refined metal.

The cost of smelting one ton of tin ore, including repairs to furnaces, cartage of ore to the works, and of metal from the works to the ship, and rent of ground on which the works stand, but not including interest on capital outlay, is as follows:

Wages and salaries	17*s.* 10*d.*
Coal (1.02 tons used for smelting)	13*s.* 8*d.*
Fire-brick, etc.	1*s.* 9*d.*
Cartage, rent, lime, sundries	3*s.* 2*d.*
Total	$8.85, or 36*s.* 5*d.*

From the published reports of the Company it would appear that Mount Bischoff ore as it comes from the mine carries 3 to 3½% of black tin, but it is dressed up to a yield of 64 to 72% of metal, gross assay. In the half-year ending June 30, 1896, the results were as follows: Ore smelted on Company's account, 1,179.9 tons; metallic tin produced, 797.9 tons; ore smelted on public account, 748.75 tons; metallic tin produced, 519.15 tons; total ore smelted, 1,928.65 tons; total tin obtained, 1,317 tons. Of the Mount Bischoff ore the various parcels were as follows: No. 1 first quality, average net assay 68.98%, 764.45 tons; No. 1 second quality, average net assay 65.71%, 245.15 tons; No. 2 first quality, average net assay 64.26%, 170.3 tons. In the second half of that year the figures were: Ore smelted on Company's account, 1,136 tons, yielding 772.3 tons of metal; ore smelted on public account, 854.4 tons, producing 596.2 tons of tin; total ore smelted, 1,990.4 tons, producing a total of 1,368.5

tons of tin. The following were the parcels of Mount Bischoff Company's ore: No. 1 first quality, average net assay 69.06%, 809 tons; No. 1 second quality, average net assay 65.57%, 250.75 tons; No. 2 first quality, average net assay 64.53%, 76.2 tons. The net assay of the first grade is 2% less than the gross, and of the second and third qualities 3% less.*

With regard to the cost of smelting the only information that appears in the accounts is an item "Furnace working account—£2,311 14*s.* 8*d*" in the first half-year, and "£2,084 9*s.* 8*d.*" in the second. If these amounts represent the cost of smelting the above 1,317 and 1,368.5 tons of tin respectively, it will work out to £1 15*s.* 1*d.* and £1 10*s.* 6*d.* per ton respectively; obviously interest and depreciation are not included in these figures, and possibly not even general management, but it will be seen that they agree well with Mr. Latta's more detailed statement. The percentages in which various items enter into the total cost, according to another authority,† are:

Fuel	41 per cent.
Labor	43 " "
Fluxes	1 " "
General	15 " "
	100 per cent.

The furnace used in Queensland is somewhat similar to that used in Tasmania; it smelts three charges, each of 3 tons, in 24 hours, and burns 11 cords of wood in the process.

Smelting in the reverberatory furnace has for some years been employed in the Malay Peninsula; operations were commenced on a small island just to the south of the Peninsula, the little island of Pulo Brani, off Singapore, where the Straits Trading Company Limited erected works; this highly successful company subsequently built a second works at

* From the half-yearly Reports of the Directors of the Mount Bischoff Tin Mining Company Registered.

† Sixteenth Annual Report of the Director of the United States Geological Survey, p. 506.

Butterworth in Province Wellesley, opposite Penang, and another company, the Eastern Smelting Company Limited, has also started smelting works on the island of Penang itself. The process as carried out by the Straits Trading Company deserves detailed description, first of all because their works are by far the largest in the world, producing several times as much tin as the whole of Cornwall, and secondly because the process is in many respects quite novel, and has, thanks to the skill and ability of Mr. J. McKillop, who was the constructor and for many years the manager of the Pulo Brani works, attained a greater degree of scientific and technical perfection than can probably be claimed for any other tin-smelting establishment. Much of the following information has been obtained by observation on the spot, and also direct from Mr. McKillop, who has moreover described his process in a paper communicated to the Institution of Civil Engineers.* The first attempt to smelt tin in reverberatory furnaces in the Malay Peninsula was made in Perak by the Shanghai Tin Mining Company of Perak, which was, however, not successful, and had to be wound up. In 1885 the Straits Trading Company Limited was formed and recommenced operations at the abandoned works of the Shanghai Tin Mining Company at Teluk Anson on the Perak River; the new company succeeded in securing a most valuable monopoly, namely, the sole right to purchase and export tin ore from Selangor and Perak, and two years later, at the end of 1887, commenced smelting operations with one furnace on the small island of Pulo Brani, which practically forms a portion of the almost land-locked harbor of Singapore, so that every facility for unloading tin ore and coal, and for shipping the ingots, was readily obtainable. This company has been as successful commercially as it has technically, and in 1895 had in steady operation fourteen 4-ton smelting furnaces, with a well-arranged refinery, producing about 1,200 tons of ingot tin per month. At present there are some 14 reverberatory

* Vol. CXXV, 1895-96, Part III.

furnaces at Pulo Brani and eight at Penang, their capacity being about 12½ tons of tin ore in 24 hours. The total annual output is about 35,000 to 40,000 tons of tin, or a third of the world's entire output, about two-thirds being produced at Pulo Brani and one-third at Penang. The following description applies to the process as it was carried on in 1895, but it is still essentially the same to-day, the main changes having been in the direction of increasing the dimensions of the furnaces.

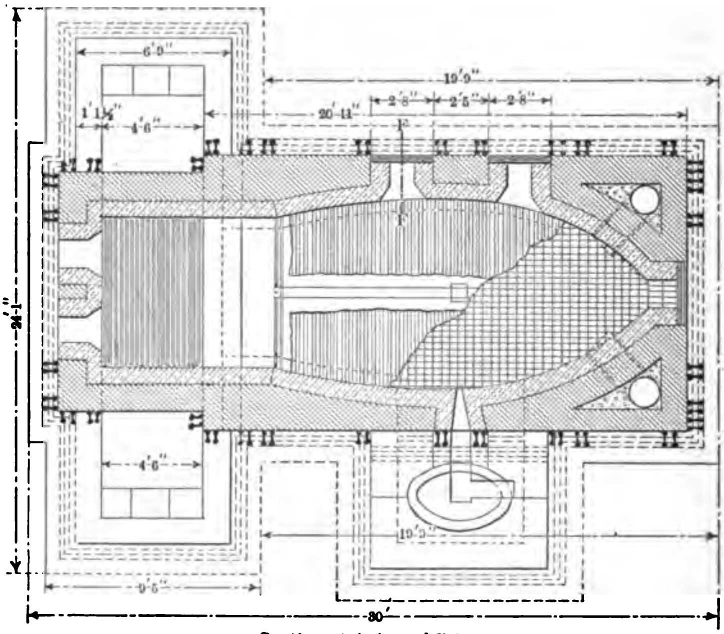
The reverberatory furnaces used for smelting present a good many novelties, the lining of the walls, the roof and the bed being so arranged that each is capable of independent renewal. The outer main walls carry the lining of fire-brick, against which the edges of the bed abut, and the arch of the roof springs also from the main walls and not from the lining, the walls being securely tied by iron buckstaves and tie-rods against the thrust thus caused. The bed is carried on transverse iron rails of a length equal to one-half the width of the bed, one end of which rests on the brickwork of the main walls and the other end on a heavy longitudinal rail; the latter is in two halves, the outer ends carried by the brickwork of the furnace, the two inner ends on a brick pier in the middle of the furnace. When this pier is knocked down, the iron-work on which the bed rests at once falls in, and the bed, of course, with it. The bed is composed of fire-brick laid on end as close up as possible, and grouted with fire-clay. It is then dried and heated, and when ready, a charge of cast-iron is melted on it, that binds every part firmly together. Every part of the bed slopes towards the tap-hole, the fall amounting to 3½ inches. The fire-bridge, which is 8 inches above the bed, is hollow and is also carried on rails; the working dimensions of the bed are: Length 16 feet, width at center 9 feet 9 inches, and at fire-bridge 6 feet, area about 125.5 square feet. A bed requires about 3,000 fire-brick, and lasts for 120 to 150 charges. A special feature is the water-vault; the lower part of the furnace foundation below the ground line is built so as to form

a water-tank extending the full length of the bed and bridge, and the full width of the bed and float. This vault is kept full of water to a depth of 8 feet; any tin that leaks through the bed, or through any joint, drops into the water and is thus granulated; once a week the water is pumped out and the granulated metal collected. Any steam generated escapes through a couple of tubes, 18 inches in diameter, built into the angles of the vault nearest the flue-end; and it is found that as long as the water-level in the vault is maintained, there is no danger of explosion. As it is absolutely impossible to prevent the leakage of so mobile and easily fusible a metal as tin, this water-vault seems to present the best method of dealing with the leakage and of promptly recovering the metal.

The dimensions of the fire-place vary, according to the kind of coal that is being used, from 4 feet by 6 feet to 4 feet 6 inches by 6 feet 9 inches, the depth being 2 feet 6 inches from the top of the fire-bridge to the bars; there are two fire-doors in the back wall high up close to the roof; these have no door proper, but are kept sealed by the coal thrown in. There is also a series of holes just above the fire-bar level, through which a bar can be introduced to keep the grate clear and to work the fire as required. The furnace proper has the usual working-door in front under the flue, and two charging-doors. The construction of the furnace is shown in Figs. 38 to 40, taken from the above quoted paper.

Coals of various kinds have been used at these works, namely, Welsh, Australian, Japanese, Indian, Borneo, and Tonquin; now, Japanese and Tonquin coals are used almost exclusively, since, although inferior to Welsh coal, they are a great deal cheaper. Welsh anthracite is imported, however, for mixing with the charges. Soft coal has been used, but is not quite as satisfactory, besides 10% more being required. The area of the flues is about 3.75 square feet, and the stacks, one to each pair of furnaces, are 100 feet in height.

The cost of a furnace with overhead flues, but without stack and including also one-half of the old form of refining pot and ingot stand (used when refining was done in these furnaces, and when one kettle was arranged between each pair of furnaces), may be taken at about £350 (exchange taken at 2*s*. to the dollar).



Section at A.A. and B.B.

FIG. 38. — Tin-smelting Furnace at Pulo Brani

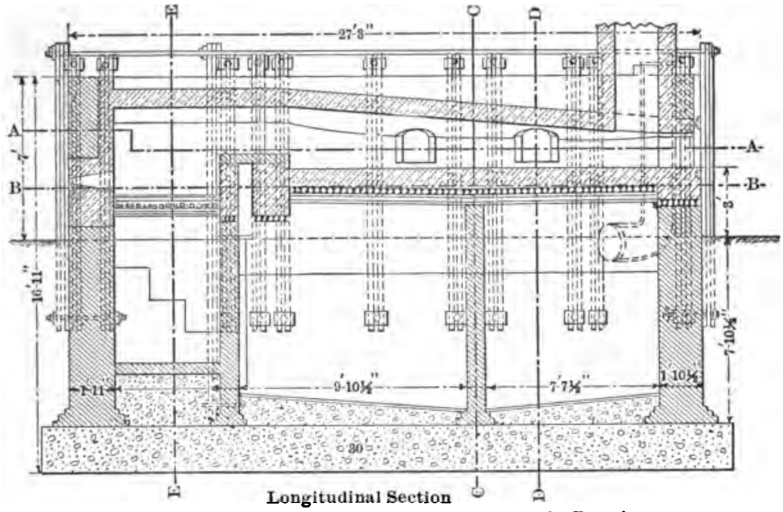
The complete process of smelting may be classified into the following four operations:

(*a*) "Ore-smelting," producing "ore metal" and "rich slag."

(*b*) "Rich slag smelting," producing "rough metal" and "poor slag."

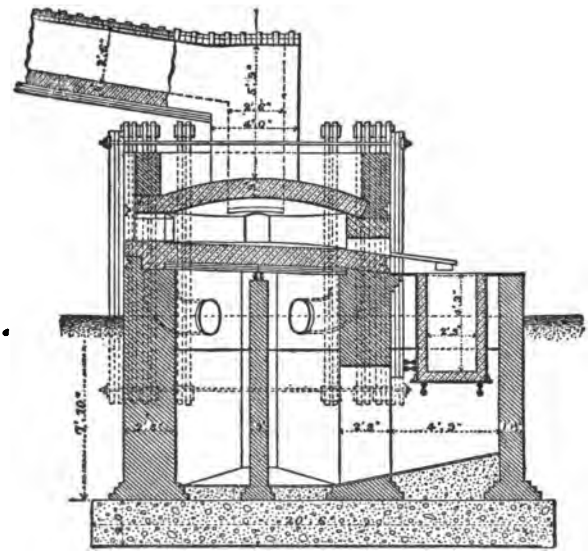
(*c*) Treatment of "poor slag," producing "prill" and clean slag.

(*d*) Refining "ore metal," "rough metal," and "prill," producing various grades of marketable tin and "refinery



Longitudinal Section

FIG. 39. — Tin-smelting Furnace at Pulo Brani



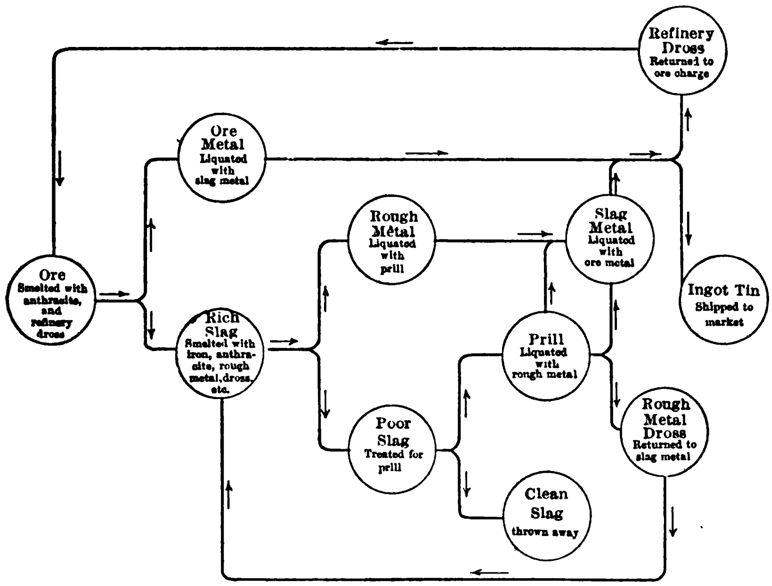
SECTION AT D D. SECTION AT C C.

FIG. 40. — Tin-smelting Furnace at Pulo Brani

dross," which is added to the "rich slag smelting charge" or to the "ore charge."

The following diagram illustrates the cycle of operations:

(*a*) As soon as a charge has been got out of the furnace, the latter is cleaned, and fettled in case of need with a mixture of fire-clay and bauxite. The materials for the next charge have meanwhile been wheeled to the furnace and deposited in front of the charging-doors. The furnace being sufficiently hot, the damper is closed and the charge is



shovelled in and spread over the bed, so that it is thickest near the fire-bridge, 2 feet from which it is 12 to 14 inches deep, though less than 6 inches deep at the front door. The doors are then tightly closed, the damper opened, and the fire made up. The composition of the charge varies somewhat according to the composition of the ore, the following being average mixtures: (1) For ore assaying 65 to 71%: Ore, 80 cwt.; culm, 10.4 cwt.; refinery dross, 2.4 cwt. (2) For ore assaying above 71%: Ore, 80 cwt.; culm, 12 cwt.; refinery dross, 2.4 cwt. At the end of 2 to $2\frac{1}{4}$ hours a fresh fire is generally needed. If the coal is good the charge can be rabbled first; if not, another fire is first put on, lasting about $1\frac{1}{2}$ hours; in either case the charge, when well rabbled,

should be all off the bed, liquid near the fire-bridge, not too pasty toward the center, and frothing feeely. Another fire is then put on, lasting about an hour, and the charge is again well rabbled; all should now be well melted, uniformly bright all over, and free from floating masses of unfused material. At this stage another good fire is put on, and the furnace is tapped by withdrawing the tapping bar that closed the tap-hole; all the tin runs out in a thin stream into the float in about ¾ hour. The bar is then put back and a gutter placed under the tap-hole so arranged as to deliver into a series of sand-beds that have been made up beside the furnace. The whole of the clay stopping of the tap-hole is then knocked out, and the slag is allowed to run in a thick stream into the sand-beds. The furnace is then ready for a fresh charge. The average time from charge to charge is 7½ to 8 hours. The products are 4,500 to 4,800 pounds of "ore metal," containing about 99.5% of tin, and 2,200 to 2,500 pounds of rich slag, assaying 20 to 40% of tin. An analysis of this slag gave: Tin, 35%; silicon, 15%; aluminum, 18%; iron, 9%; also Mg, Ti, Ca, Mn, etc. The tin produced is allowed to cool in the float until its temperature is sufficiently low to enable it to be ladled into iron ingot moulds; the metal is dull grayish and somewhat hard and brittle, and it is sent into the refinery to be subsequently refined.

(*b*) The rich slag is next smelted, this operation being performed in the same kind of furnace that is used for ore-smelting; it is usual to put a newly built or repaired furnace on slag charges; slag-smelting requires a higher temperature than ore-smelting, and the metal produced has a considerably higher melting point, hence this smelting is of use in filling up any crevices or stopping any leaks in the new work. Similarly, when a furnace is getting worn out and is leaking seriously, a few charges of slag will often remedy the evil, at any rate temporarily. An average charge is made up as follows: Rich slag, 30 cwt.; rough metal dross, 12 cwt.; scrap iron, 2.75 cwt.; anthracite,

6 cwt.; coral, 2.4 cwt. The "rough metal dross" is a product of the refining of the metal produced in this fusion.

A good fire is put on, and then usually a second, after which the charge is rabbled in some three hours or so from the start, and in another hour the charge is usually well off the bed and pretty well ready for tapping. The entire operation takes about 7 hours. The products are 1,800 to 2,000 pounds of "rough metal" and about 2,400 pounds of "poor slag." The former is either run into the float, whence it is ladled into moulds, being stirred continuously while settling, or it is run direct into sand moulds or granulated in water, the last being apparently the most satisfactory mode of procedure. Good rough metal contains about 95.5% of tin, the rest being chiefly iron; it is dull blackish-gray in color, and very brittle. The slag is black and glassy, very variable in composition, but averaging about 60% of silica; it should not contain more than 2.5% of tin combined with silica, but may contain up to 10% in the form of prills of rough metal. As a rule all the prills are contained in the two first pigs of slag; the others are examined, and if found free from prills are thrown away. Two-thirds of the slag produced is thus got rid of at once.

(*c*) The slag that contains prills of metal is broken up and any large lumps of metal are extracted; the slag may then be stamped and washed, but the brittle rough metal is apt to be slimed and thus lost. It is hence found preferable to fuse the slag with the addition of a little culm and lime. An average charge would be: Poor slag, 40 cwt.; culm, 2.5 cwt.; coal, 2.5 cwt. This is melted and rabbled once or twice, after which the slag is tapped off, the process taking 5 to 6 hours. The metal is allowed to accumulate in the furnace and is tapped every two days or so, being treated exactly like rough metal, which it greatly resembles in appearance. It contains, however, rather more iron, and is often spoken of as "hardhead." Its average composition is: Tin, 80.5%; iron, 19.5% — total, 100%. The slag thrown away amounts to about 27% of the weight of the

ore originally started with; on the average it may be taken as containing 5% of tin, though a good deal is much poorer than this. This average would correspond to a loss of tin equal to 1.35% of the ore, or taking the latter to contain 70% of tin, a loss of about 2% of the metal present. There are no losses, except such as are due to splashing, etc., in any other parts of the process, since all the products of refining are continuously returned to the furnaces. The whole of the iron added in the slag-smelting is thrown away in the slag, the iron in the rough metal being practically derived from the rough metal dross, and simply circulating, so to speak. The consumption of iron amounts to 4.7% of the tin produced, and that of culm amounts to about 27% of the tin produced.

(*d*) The metal produced from 100 parts of tin ore is now distributed somewhat as follows: (1) Ore metal 58 parts, containing 57.7 parts of tin; (2) rough metal 9 parts, containing 8.6 parts of tin; (3) rough metal from prill 2 parts, containing 1.6 parts of tin; together with slag 27 parts, containing 1.4 parts of tin — total, 69.3. The last item is, of course, the loss. The ore metal is ready for the refinery, while the rough metal obtained from operations (*b*) and (*c*) undergoes a preliminary refining in the smelting house. A smelting furnace is charged with either granulations or ingots that have been stirred while setting, and the heat is brought up to dull redness using wood as fuel. The results are 90% of "slag metal," containing about 99.5% of tin, and hence practically identical with ore metal, and "rough metal dross"; the latter contains much metallic tin and iron and oxides of these metals, together with those of most of the impurities present in the rough metal. This dross contains on the average: Tin, 65%; iron, 25.5%. As previously stated, it forms part of the slag-smelting charge, and thus all the tin in it returns into the cycle of the furnace operations. The slag metal is cast into moulds like the ore metal, and the two are sent to the refinery together.

The refining furnace or liquating furnace consists of

a reverberatory furnace with a fire-place at either end and a flue in the center of the arch. The bed is 10 feet long and 6 feet wide, with two shallow transverse depressions or troughs running across it, opposite to each tap-hole and inclining in the direction of its width, with a fall of about 1 foot. At the lower side there are two tap-holes with spouts leading to floats 3 feet 6 inches in diameter, capable of holding about 7 tons of tin each. At the higher side of the furnace there are four charging-doors. The arch is 6 feet high in the center. The fire-places have a grate area of 6 feet 6 inches by 11 feet, and each has a fire-door in its respective furnace-end; the fuel used is mostly wood, but coal has been used. The temperature is maintained as little as possible above the melting point of pure tin, and the furnace body is kept full of smoke so that the atmosphere shall be a reducing one. The fuel consumption, when coal is used, is about 100 pounds to the ton of tin refined. The ingots of tin, weighing about 100 pounds each, are piled on the upper portion of the bed, and as they melt down slowly, the liquated tin runs into one or other of the floats which are placed in the pouring house, a gray pulverulent mass, known as refinery dross (which is added, as before stated, to the ore-furnace charges), being left behind on the furnace bed. This dross contains: Tin, 65%; iron, 11.5%, a considerable proportion of these metals being in the state of oxide. Every 100 parts of ore metal will give about 96.5 parts of refined metal and 4.5 to 5 parts of refinery dross. The tin in the floats is allowed to stand at rest for about one hour, and is then ladled into one of a set of four large kettles set over a small fire-place, and situated at a level about two feet below the smaller floats.. Each of these large kettles is 8 feet in diameter and holds about 30 tons. The tin is thus made to undergo a tossing process during the operation of being ladled from the one kettle to the other. If the tin is not now sufficiently soft, it is "boiled" in the usual way, but this operation is more often performed before the metal is sent to the refinery, if at all.

The metal is allowed to stand for 24 hours in the large kettles at a temperature just above its melting point; all impurities are thus given sufficient time to settle to the bottom of the kettle; the surface is then skimmed and the tin ladled out into moulds, the ingots weighing about 100 pounds, at least 25 tons of the tin being so cast. The bottom 12 inches of metal in the kettle are ladled into separate moulds and is sent back to the refinery to be liquated over again.

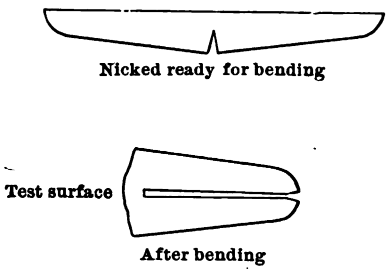


FIG. 41. — Tin Test Piece — Width 1¼ inches

The metal thus produced should be white, bright colored, and should show a slight depression in the center. A sample cut from any of the corners should, if cut half through and then bent, show a smooth, almost silky surface, free from harsh projecting lumps or grains. During the process of casting, samples are continually taken and tested, the shape of the test piece being shown in the accompanying figure (Fig. 41).

The following is an analysis, made in 1892, of an average sample of Pulo Brani tin:

Sn	99.76%
Sb	0.07%
Pb	0.02%
Fe	0.14%
Cu, As	none
Total	99.99%

The cost of the smelting operations cannot be given with absolute accuracy; at the works it was always taken as

ranging between $1.15 and $1.25 per picul (say 39*s*. to 42*s*. per ton), but it varies of course considerably with the rate of exchange, and the very variable price of coal, which ranged from 18*s*. to 27*s*. per ton. The following shows very nearly the cost of operations about the year 1888, and this does not seem to have undergone much modification since that time, allowing for the depreciation in the value of silver:

	Per ton of 2,240. pounds of ore
Fixed charges,* including rent, maintenance, office expenses, management, European supervision, etc.	7*s*. 5*d*.
Native labor of all kinds,	4*s*. 8*d*.
Coal, 0.98 tons at 20*s*. 6*d*. per ton	20*s*. 1*d*.
Culm, 3.4 cwt. at 27*s*. per ton	4*s*. 7*d*.
Materials, iron, lime, boilwood, water, etc.	11*d*.
Repairs to tools and furnaces	1*s*. 6*d*.
Total cost per ton of ore	39*s*. 2*d*.
Equivalent to about 56*s*. per statute ton of metallic tin, or $12 per ton of 2,000 pounds	

It has been already stated that all the ore is bought, generally through agencies, in the various Native States, the following being the system of payment adopted by the Straits Trading Company: The ore is weighed and 3 to 5% is deducted for moisture. It is then assayed by the cyanide method, and a deduction made for the supposed loss in smelting as judged by the softness and general character of the assay button, this first deduction being from 0.25 to 5%, or sometimes more. From the percentage of gross tin thus obtained, a second deduction for loss in smelting is made according to the following scale: From ores giving over 70% gross, 2% is deducted; from 67.5 to 70%, 3% is deducted; from 65 to 67.5, 4% is deducted, and below 65% the scale of deductions increases still more rapidly. If the assay shows the presence of very much impurity, a still higher deduction is made. From the weight of the dry ore and reduced assay value thus obtained, the weight of tin is calculated and is paid for in cash at the current market rate less a deduction of $1.75 per picul of ore (about £2 18*s*. 10*d*.

* The Straits dollar is throughout these calculations taken at 2 shillings or 48 cents United States currency.

per statute ton), of which $1.50 per picul (about £2 10*s.* 5*d.* per ton) is supposed to be for smelting charges and the remainder for profit. From the figures quoted above, the company has evidently allowed itself a liberal margin, although it must not be forgotten that it has to pay agency, transport, and a few other similar charges in addition to smelting charges proper.

Mr. L. Linaud* states that ore is now bought at a price calculated as follows: The purchase price in Straits dollars per picul = (T — 2) (C — 2.21 — 0.7n), where T is the commercial assay of the ore, C is the value of Straits tin in dollars per picul, and n is the export duty, which fluctuates with the price of tin. When the ore is arsenical or sulphury, an amount that amply covers the cost of roasting is also deducted.

In 1893 the Pulo Brani works smelted 13,500 tons of ore and produced 10,470 tons of tin; in 1894 the output rose by about another 500 tons, and has since then been increasing steadily to the high figure already stated.

At the Penang works the process is practically the same; one of the modifications has been the firing of some of the furnaces with oil fuel, which is quite successful.†

Oil fuel had previously been used at the Temescal Mines in California‡ in the years 1890–92. The black tin produced here assayed about 65% of metal; it was smelted in a reverberatory furnace with a bed measuring 10 ft. 6 in. by 11 ft.; using Californian petroleum for fuel and New Mexico coal as a reducing agent. Coal cost $10.50 per ton of 2,000 lbs. at the mines and petroleum 4.2 cents per gallon, which was probably equivalent to coal at $6 per ton. The charge consisted of 1,800 lbs. of black tin with 20% of coal, and three charges were smelted in 24 hours. The slags assayed about 5% of tin and were re-stamped. The cost

* *Mem. et Tran. de la Soc. des Ingénieurs Civils de France,* 1909, Vol. I., p. 47.

† Communicated by the Managing Director.

‡ *The Mineral Industry,* Vol. V, p. 587.

of smelting was about $9 per ton, exclusive of general expenses, and the tin was about equal to the best Cornish in quality. About 135 tons (or 2,000 lbs.) of tin were produced before the mines were closed down.

It will be seen from the above description that the Pulo Brani practice presents the highest stage of development of the process of tin-smelting. Beginning with the most rudimentary methods, which were evidently the primitive ones in all parts of the world where tin has been found, we have been able to trace their step-by-step development and the causes that led to the adoption of the more scientific reverberatory furnace, and of the few improvements which this process has since undergone. It is in the highest degree significant that the chief improvements have originated in the Pulo Brani works, which are by far the largest works in the world. There is no doubt that we have in these facts the clue to one of the main reasons why the metallurgy of tin has not kept pace in any measure at all with that of the other common metals, it being remembered that of all the common metals tin is by far the rarest. Comparing, for instance, the world's annual output of these metals, in say 1908, namely: Lead 1,000,000 tons, zinc 725,000 tons, copper 750,000 tons, with that of tin, amounting to about 110,000 tons, the difference is sufficiently striking; at the same time it must be borne in mind that individual copper works produce in some years as much as 50,000 tons of copper, or nearly half as much as the world's output of tin, and much more than the tin production of the Pulo Brani works, eminent though the latter is, as we have seen, among tin producers. As is always the case, when metallurgical operations are conducted on a small scale, they are surrounded with secrecy, in consequence of which improvements come slowly, and ancient methods survive with surprising tenacity of life. So far no electrical or wet methods have proved of the slightest use in the extraction of tin from its ores, and in spite of the proverbial danger of prophesying, it seems as though it may fairly be expected that a good many

years will yet pass away before any very radical advances in the art of tin-smelting will have to be chronicled.

For obvious reasons it is out of the question to extract tin from its ore by any electrolytic method. Such methods have been applied to some extent to the treatment of the by-products obtained in smelting, such as slag and hard-head, but have never yet passed the experimental stage. Such a process is that proposed by E. Bohne and which was tried for the treatment of tin slag, which can rarely be obtained in the ordinary smelting processes with much less than 4% of tin. Bohne granulates the slag by running them from the furnace into cold water; the granulated or finely ground slag is treated in lead-lined wooden vessels with hot dilute sulphuric acid, which produces a partly gelatinous, partly granular, residue of silica, containing a little tin, and a solution containing tin and iron. The solution is electrolyzed to separate the tin and the mother liquor is subsequently evaporated, yielding crystallized ferrous sulphate; the silicious residue is used in making up the beds of the reverberatory furnaces.* The process does not seem to have come into extended use. The main application of electrolytic methods has hitherto been to the treatment of tin-plate scrap, in connection with which they will be discussed.

* *Berg und Hüttenmannische Zeitung*, 1898, LVII., p. 203.

CHAPTER V

TIN-PLATE AND TIN-PLATE SCRAP

MANUFACTURE OF TIN-PLATE

THIS consists in rolling iron or steel into sheets of the required thickness, pickling the sheets in order to remove the coating of oxide that covers them, then immersing them in a bath of molten tin, in order to "tin" them, and finally removing the surplus tin. In the original method iron made in the finery was alone employed, but after a time puddled iron was also used. The older process of producing tin-plates is described with minute accuracy by Percy in his classical work on Iron and Steel,* and a paper in 1883 by Mr. E. Trubshaw † shows the first introduction of modern methods. About 1878 the first attempts were made to replace iron by open-hearth steel, and nowadays mild steel is used almost exclusively for this purpose. Tin-plate bars are now made of steel having about the following composition:

Carbon	0.1%
Silicon	0.02 to 0.03%
Sulphur	0.04 to 0.06%
Phosphorus	0.09 to 0.1 %
Manganese	0.53 to 0.45%

It is rolled into bars about ½ inch thick and 8 to 10 inches wide, and these may be looked upon as the raw material for the manufacture of tin-plates.

These bars are cut into short pieces, heated in a reheating furnace, and rolled into sheets. When thin enough they

* *Iron and Steel,* by Dr. John Percy, 1864, p. 725.

† "On the Tin Plate Manufacture," by Mr. Ernest Trubshaw, *Jour. Iron and Steel Inst.,* 1883, I, p. 252.

are doubled over and rolled further, again doubled, and so on until they are sufficiently thin, being again heated as may be required between the successive rolling operations. The bundles of sheets thus produced are then sheared to the required size, and the sheets are then opened or separated from each other. This opening is still done by hand in many places, though quite satisfactory rolling machines have been introduced to perform this work. Such a machine is fully described in a recent paper on tin-plate manufacture by Mr. G. B. Hammond.*

The rough black plates thus produced are next pickled to remove the layer of scale from their surface; this is done by immersing the plate in acid — usually dilute sulphuric acid — in a machine provided with rocking cradle, in which the plates are first pickled and then thoroughly washed. The plates are then annealed at a low red heat for some 8 or 10 hours in iron or steel pots, and allowed to cool slowly, after which they are cold-rolled between polished chilled rolls and then annealed again, followed by a second or "white" pickling. The old method of tinning was to immerse the plates in molten palm oil and then in a series of pots containing molten tin, each being covered with a layer of palm oil. The modern method consists of passing them by mechanical means through a bath of molten chloride of zinc, then through one of molten tin, and finally through a pair of rolls revolving in a bath of palm oil, by means of which the superfluous tin is removed and the coating of tin maintained exactly at any desired thickness. The various machines in use for this purpose are described in the paper by Mr. Hammond already referred to. The grease is removed from the surface of the plates by rubbing with bran, and they are finally polished by passing between rollers covered with sheepskin. The cost of producing a box of standard 14×20 I. C. coke finish plates is estimated at about 13*s.*, out of which about 2*s.* 6*d.* represents the cost of labor. Such

*"The Manufacture of Tin-plates," by George B. Hammond, *Jour. Iron and Steel Inst.*, 1897, II, p. 24.

a box contains 112 sheets, each weighing almost 1 pound, whilst the weight of tin in the box will be a little over 2 pounds. Roughly, it may be taken that ordinary tin-plate contains 2 to 3% of its weight of tin.

Terne plates are plates similarly coated with an alloy of tin and lead; they are used for some special purposes, such as roofing.

RECOVERY OF TIN FROM TIN-PLATE SCRAP

Tin-plate scrap consists either of old tins that have already done duty, or of the clippings produced in the manufacture of tin-plate articles, the former constituting by far the larger quantity, whilst it is at the same time much the more difficult to treat, as it is greasy and dirty, and also contains solder. The technical problem consists of the recovery, in suitable form, of both the tin and the iron present, and whilst the difficulties of devising a suitable process are considerable, the economic difficulty, namely, that of obtaining sufficiently large quantities of the material at any one center to be worth treating, is also a serious one.

Some of the earlier attempts were purely mechanical, as for instance heating the scrap with sand in revolving cylinders; it is said that by these means solder can be removed, but very little tin. The tin can be dissolved off in the wet way by hydrochloric acid, by ferric chloride, or by alkalies in the presence of air or some oxidizing agent; the resulting solutions can either be utilized as such or can be electrolyzed. The most successful method is one that has recently been devised by Dr. R. Goldschmidt at Essen, which consists in treating the scrap with dry chlorine gas in iron cylinders which are carefully cooled. The use of chlorine for "detinning" tin-plate scrap was first suggested by Higgins in 1854, but Lambotte first worked out a practical process in 1884. This was displaced by electrolytic methods, and the latter are now giving way to the Goldschmidt chlorine process. Clean tin-plate cuttings only need pressing into bundles for treatment. Old tins are passed between

toothed rolls that flatten and perforate them; they are washed in an alkaline bath to remove grease, rinsed in clean water, then heated in a furnace to remove solder, and to destroy any india-rubber, etc., that may be present. The tins thus cleaned are pressed into bundles and transferred to the iron cylinder, into which chlorine is admitted, under a pressure of several atmospheres; the cylinder must be carefully cooled, since the action of chlorine upon tin develops an amount of heat of over 1000 calories; as soon as the pressure remains constant the process is finished, the whole of the tins having been converted into liquid stannic chloride. This salt together with the excess of chlorine is removed, the bundles of iron are taken out, well washed, and are then ready for charging into the open-hearth steel furnace. By this process the percentage of tin remaining in the steel is reduced to below 0.1%. It is stated that this process treats in Germany annually 50,000 tons of tin-plate scrap, this being two thirds of the total amount treated in Germany, and it recovers 1,500 tons of tin, or its equivalent in the form of tin-salts.*

The only electrolytic method that appears to have been at all successful, and which is in use in several of the smaller works, consists in using tin clippings contained in iron baskets as anodes, plates of iron forming the cathodes, whilst the electrolyte consists of a solution of caustic soda containing about 5% of Na_2O, which must be kept heated to about 60° or 70° C. and in constant circulation. The tin is deposited at the cathode in a condition varying from spongy to fine granular, and is melted down in a bath of tin; the product is fair commercial block tin containing 97 to 98% of tin, the chief impurity being lead. At a tension of 1.5 volts it takes 5 to 7 hours to remove the tin from a basket containing 1 cwt. of tin-plate scrap. It is practically impossible to completely remove the tin from the cuttings, the residual iron always retain-

* *Öst. Zeitsch. f. Berg. u. Hütt.-Wesen,* Vol. LVII, 1909, p. 103. *Zeitsch. f. Angewandte Chemie,* 1909, p. 1.